IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

SYMBOL TECHNOLOGIES, INC., a Delaware corporation, and WIRELESS VALLEY COMMUNICATIONS, INC., a Delaware corporation,	)	C.A. No. ____________
Plaintiffs,	)	
v.	)	**JURY DEMANDED**
ARUBA NETWORKS, INC., a Delaware corporation,	)	
Defendant.	)	

COMPLAINT FOR PATENT INFRINGEMENT

Plaintiffs Symbol Technologies, Inc. ("Symbol") and Wireless Valley Communications, Inc. ("Wireless Valley") (collectively "Plaintiffs"), by their counsel, as and for their Complaint against Defendant Aruba Networks, Inc. ("Aruba"), allege as follows:

PARTIES

1. Symbol is a Delaware corporation having its principal place of business at One Motorola Plaza, Holtsville, New York 11742-1300. Symbol develops and markets innovative, high-performance products, including, *inter alia*, wireless local area networks ("WLANs") and their components, including wireless access points and wireless switches. Symbol is a wholly-owned subsidiary of Motorola Inc.

2. Wireless Valley is a Delaware corporation having its principal place of business at 4515 Seton Center Parkway, Suite 330, Austin, Texas 78759. Wireless Valley is a leading provider of software solutions for the design and management of WLANs. Wireless Valley is a wholly-owned subsidiary of Motorola, Inc.

3. Upon information and belief, Aruba is a Delaware corporation having its principal place of business at 1322 Crossman Ave., Sunnyvale, CA 94089-1113. Aruba maintains The Corporation Trust Company as its registered agent for the service of process in Delaware. Aruba designs, manufacturers, and sells in the United States wireless switches (which it calls mobility controllers), access points, management servers, and related software for use in connection with WLANs, as well as software for designing, planning, configuring, monitoring, managing, and optimizing WLANs.

JURISDICTION AND VENUE

4. This is an action arising under the patent laws of the United States, 35 U.S.C. §§ 101 *et seq*. This Court has subject matter jurisdiction pursuant to 35 U.S.C. § 271 *et seq.* and 28 U.S.C. §§ 1331 and 1338.

5. Venue is proper in this judicial district under 28 U.S.C. §§ 1391 and 1400.

6. This Court has personal jurisdiction over Aruba because Aruba is a Delaware corporation with an agent for service of process in Delaware. Upon information and belief, Aruba also places its infringing products in the stream of commerce, which stream is directed at this district.

THE PATENTS

7. Symbol is the owner by assignment of United States Letters Patent No. 7,173,922 ("the '922 Patent"), entitled "Multiple Wireless Local Area Networks Occupying Overlapping Physical Spaces." The '922 Patent duly and legally issued Feb. 6, 2007. A copy of the '922 Patent is attached to this Complaint as Exhibit A.

8. Symbol is the owner by assignment of United States Letters Patent No. 7,173,923 ("the '923 Patent"), entitled "Security In Multiple Wireless Local Area Networks." The '923 Patent duly and legally issued Feb. 6, 2007. A copy of the '923 Patent is attached to this Complaint as Exhibit B.

9. Symbol is the owner of all rights, title and interest in and to the '922 Patent and '923 Patent (collectively "the Symbol Patents") and is entitled to sue for past and future infringement of those patents.

10. Wireless Valley is the owner by assignment of United States Letters Patent No. 6,625,454 ("the '454 Patent"), entitled "Method and System for Designing or Deploying a Communications Network Which Considers Frequency Dependent Effects" The '454 Patent duly and legally issued Sept. 23, 2003. A copy of the '454 Patent is attached to this Complaint as Exhibit C.

11. Wireless Valley is the owner by assignment of United States Letters Patent No. 6,973,622 ("the '622 Patent"), entitled "System and Method for Design, Tracking, Measurement, Prediction and Optimization of Data Communications Networks." The '622 Patent duly and legally issued Dec. 6, 2005. A copy of the '622 Patent is attached to this Complaint as Exhibit D.

12. Wireless Valley is the owner of all rights, title and interest in and to the '454 Patent and '622 Patent (collectively "the Wireless Valley Patents") and is entitled to sue for past and future infringement of those patents.

FIRST CLAIM FOR RELIEF
(INFRINGEMENT OF THE '922 PATENT)

13. Plaintiffs repeat and reallege the allegations in paragraphs 1-12 as if fully set forth herein.

14. Aruba has imported into the United States, made, used, sold and/or offered for sale in the United States, products covered by the '922 Patent and/or products that when used in accordance with their instructions practice the methods covered by the '922 Patent.

15. Aruba has had actual and/or constructive notice and knowledge of the '922 Patent. The filing of this Complaint also constitutes notice in accordance with 35 U.S.C. § 287. Despite such notice, Aruba continues to import, make, use, sell and/or offer for sale in the United States products covered by the '922 Patent and/or products that when used in accordance with their instructions practice the methods covered by the '922 Patent.

16. Aruba has infringed and/or induced the infringement of and/or contributed to the infringement of the '922 Patent by importing, making, using, offering for sale, or selling in the United States, or by intending that others import, make, use, offer for sale, or sell in the United States, products that are covered by the '922 Patent and/or products that when used in accordance with their instructions practice the methods covered by the '922 Patent.

17. On information and belief, Aruba's infringement of the'922 Patent is willful. The continued infringement of the '922 Patent by Aruba has damaged and will continue to damage Symbol.

18. The infringement of the '922 Patent by Aruba has caused and will continue to cause Symbol irreparable harm unless preliminarily and permanently enjoined by the Court. Symbol has no adequate remedy at law.

SECOND CLAIM FOR RELIEF
(INFRINGEMENT OF THE '923 PATENT)

19. Plaintiffs repeat and reallege the allegations in paragraphs 1-12 as if fully set forth herein.

20. Aruba has imported into the United States, made, used, sold and/or offered for sale in the United States, products covered by the '923 Patent.

21. Aruba has had actual and/or constructive notice and knowledge of the '923 Patent. The filing of this Complaint also constitutes notice in accordance with 35 U.S.C. § 287. Despite such notice, Aruba continues to import, make, use, sell and/or offer for sale in the United States products covered by the '923 Patent.

22. Aruba has infringed and/or induced the infringement of and/or contributed to the infringement of the '923 Patent by importing, making, using, offering for sale, or selling in the United States, or by intending that others import, make, use, offer for sale, or sell in the United States, products that are covered by the '923 Patent.

23. On information and belief, Aruba's infringement of the '923 Patent is willful. The continued infringement of the '923 Patent by Aruba has damaged and will continue to damage Symbol.

24. The infringement of the '923 Patent by Aruba has caused and will continue to cause Symbol irreparable harm unless preliminarily and permanently enjoined by the Court. Symbol has no adequate remedy at law.

THIRD CLAIM FOR RELIEF
(INFRINGEMENT OF THE '454 PATENT)

25. Plaintiffs repeat and reallege the allegations in paragraphs 1-12 as if fully set forth herein.

26. Aruba has imported into the United States, made, used, sold and/or offered for sale in the United States, products covered by the '454 Patent and/or products that when used in accordance with their instructions practice the methods covered by the '454 Patent.

27. Aruba has had actual and/or constructive notice and knowledge of the '454 Patent. The filing of this Complaint also constitutes notice in accordance with 35 U.S.C. § 287. Despite such notice, Aruba continues to import, make, use, sell and/or offer for sale in the United States products covered by the '454 Patent and/or products that when used in accordance with their instructions practice the methods covered by the '454 Patent.

28. Aruba has infringed and/or induced the infringement of and/or contributed to the infringement one or more claims of the '454 Patent by importing, making, using, offering for sale, or selling in the United States, or by intending that others import, make, use, offer for sale, or sell in the United States, products covered by the '454 Patent and/or products that when used in accordance with their instructions practice the methods covered by the '454 Patent.

29. On information and belief, Aruba's infringement of the '454 Patent is willful. The continued infringement of the '454 Patent by Aruba has damaged and will continue to damage Wireless Valley.

30. The infringement of the '454 Patent by Aruba has caused and will continue to cause Wireless Valley irreparable harm unless preliminarily and permanently enjoined by the Court. Wireless Valley has no adequate remedy at law.

FOURTH CLAIM FOR RELIEF
(INFRINGEMENT OF THE '622 PATENT)

31. Plaintiffs repeat and reallege the allegations in paragraphs 1-12 as if fully set forth herein.

32. Aruba has imported into the United States, made, used, sold and/or offered for sale in the United States, products covered by the '622 Patent and/or products that when used in accordance with their instructions practice the methods covered by the '622 Patent.

33. Aruba has had actual and/or constructive notice and knowledge of the '622 Patent. The filing of this Complaint also constitutes notice in accordance with 35 U.S.C. § 287. Despite such notice, Aruba continues to import, make, use, sell and/or offer for sale in the United States products covered by the '622 Patent and/or products that when used in accordance with their instructions practice the methods covered by the '622 Patent.

34. Aruba has infringed and/or induced the infringement of and/or contributed to the infringement of one or more claims of the '622 Patent by importing, making, using, offering for sale, or selling in the United States, or by intending that others import, make, use, offer for sale, or sell in the United States, products that are covered by the '622 Patent and/or products that when used in accordance with their instructions practice the methods covered by the '622 Patent.

35. On information and belief, Aruba's infringement of the '622 Patent is willful. The continued infringement of the '622 Patent by Aruba has damaged and will continue to damage Wireless Valley.

36. The infringement of the '622 Patent by Aruba has caused and will continue to cause Wireless Valley irreparable harm unless preliminarily and permanently enjoined by the Court. Wireless Valley has no adequate remedy at law.

WHEREFORE, Symbol and Wireless Valley pray for a relief and judgment against Aruba as follows:

A. Adjudging that Aruba is infringing the Symbol Patents and the Wireless Valley Patents;

B. Adjudging that the infringement by Aruba of the Symbol Patents and the Wireless Valley Patents was willful, and that the continued infringement by Aruba of the Symbol Patents and Wireless Valley Patents is willful;

C. Entering an order preliminarily and permanently enjoining Aruba from any further acts of infringement of the Symbol Patents and the Wireless Valley Patents;

D. Awarding Wireless Valley damages in an amount adequate to compensate for the infringement by Aruba of the Wireless Valley Patents, but in no event less than a reasonable royalty under 35 U.S.C. § 284;

E. Entering an order trebling any and all damages awarded to Wireless Valley by reason of the willful infringement by Aruba of the Wireless Valley Patents, pursuant to 35 U.S.C. § 284;

F. Awarding Symbol damages in an amount adequate to compensate for the infringement by Aruba of the Symbol Patents, but in no event less than a reasonable royalty under 35 U.S.C. § 284;

G. Entering an order trebling any and all damages awarded to by reason of the willful infringement by Aruba of the Symbol Patents, pursuant to 35 U.S.C. § 284;

H. Entering an order awarding Symbol and Wireless Valley interest on the damages awarded and their costs pursuant to 35 U.S.C. § 284;

I. Declaring this an exceptional case and awarding Symbol and Wireless Valley their costs, expenses, and reasonable attorneys' fees pursuant to 35 U.S.C. § 285 and all other applicable statutes, rules, and common law; and

J. Awarding Symbol and Wireless Valley such other and further relief as the Court may deem just and proper.

JURY DEMAND

Symbol and Wireless Valley hereby demand trial by jury on all issues in its Complaint.

Respectfully submitted,

POTTER ANDERSON & CORROON LLP

By: Richard L. Horwitz by DEM (3983)

Richard L. Horwitz (#2246)
David E. Moore (#3983)
Hercules Plaza, 6th Floor
1313 N. Market Street
Wilmington, Delaware 19801
Tel: (302) 984-6000
rhorwitz@potteranderson.com
dmoore@potteranderson.com

Attorneys for Plaintiffs Symbol Technologies, Inc. and Wireless Valley Communications, Inc.

OF COUNSEL

Eric J. Lobenfeld
Ira J. Schaefer
Lawrence Brocchini
Arun Chandra
HOGAN & HARTSON L.L.P.
875 Third Avenue
New York, New York 10022
Tel: (212) 918-3000

Date: August 27, 2007
809726 / 32106

EXHIBIT A

US007173922B2

(12) **United States Patent**
Beach

(10) **Patent No.: US 7,173,922 B2**
(45) **Date of Patent: *Feb. 6, 2007**

(54) **MULTIPLE WIRELESS LOCAL AREA NETWORKS OCCUPYING OVERLAPPING PHYSICAL SPACES**

(75) Inventor: **Robert Beach**, Los Altos, CA (US)

(73) Assignee: **Symbol Technologies, Inc.**, Holtsville, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 704 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **09/780,741**

(22) Filed: **Feb. 9, 2001**

(65) **Prior Publication Data**

US 2001/0055283 A1 Dec. 27, 2001

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/528,697, filed on Mar. 17, 2000.

(51) **Int. Cl.**
H04Q 7/24 (2006.01)
H04L 12/28 (2006.01)
H04L 12/56 (2006.01)

(52) **U.S. Cl.** **370/338**; 370/466; 370/401

(58) **Field of Classification Search** 370/338, 370/328, 333, 334, 339, 343, 400, 401, 491, 370/492, 465, 466, 469
See application file for complete search history.

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U.S. Appl. No. 09/457,624, filed Dec. 8, 1999, “Flexible Wireless LAN Architecture based on wireless communications server,” Grau et al.

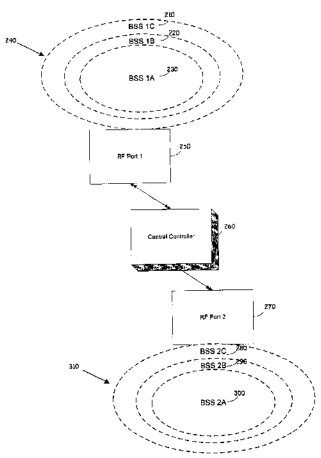
(Continued)

Primary Examiner—Chirag Shah
(74) *Attorney, Agent, or Firm*—Ingrassia Fisher & Lorenz, P.C.

(57) **ABSTRACT**

A wireless local area network is provided with simplified RF ports which are configured to provide lower level media access control functions. Higher level media access control functions are provided in a cell controller, which may service one or more RF ports that are capable operating with at least two wireless local area subnetworks occupying common physical space. Mobile units can also be configured with the higher level media access control functions being performed in a host processor.

45 Claims, 7 Drawing Sheets



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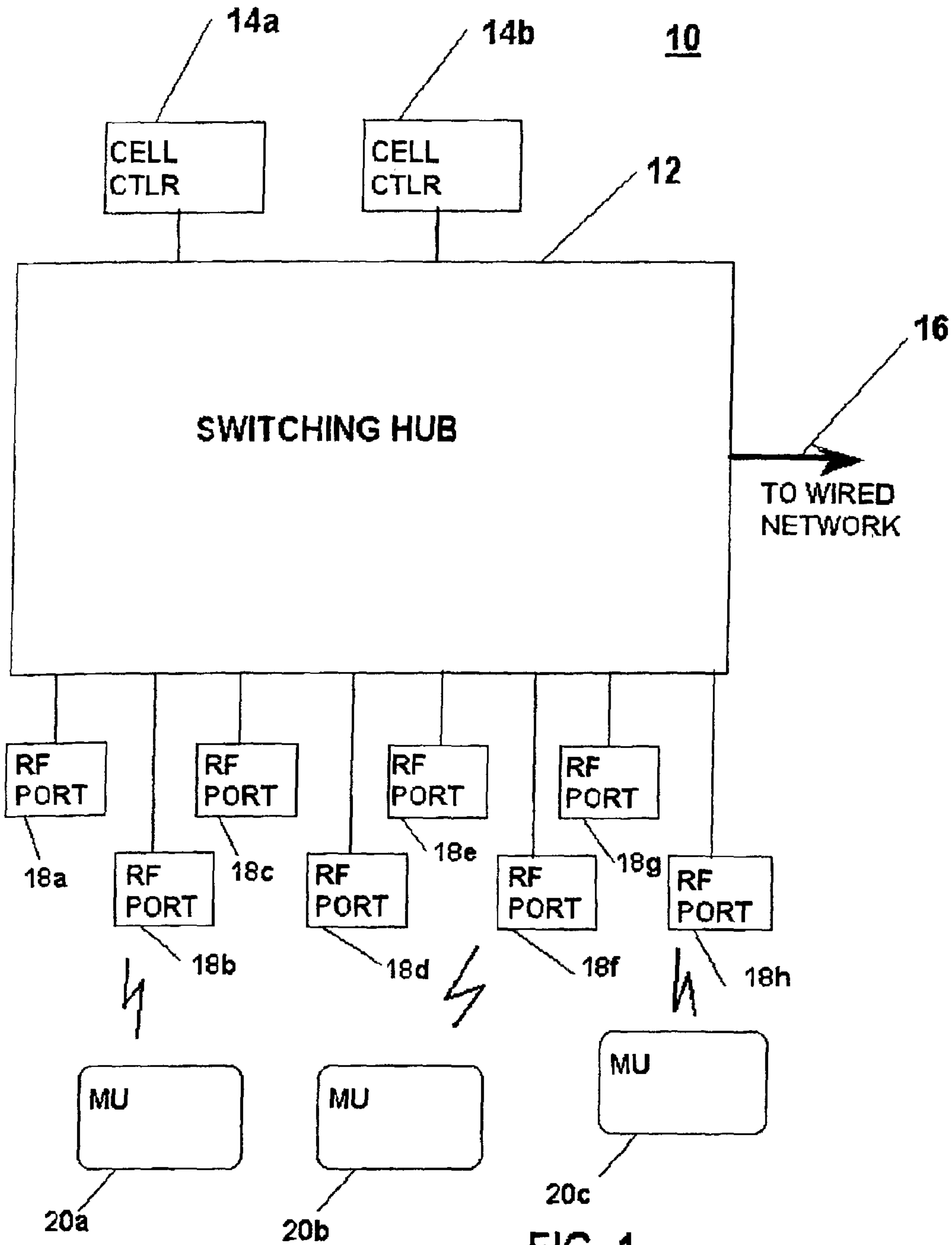

14a
14b
10
CELL CTLR
CELL CTLR
12
16
SWITCHING HUB
TO WIRED NETWORK
RF PORT
RF PORT
RF PORT
RF PORT
RF PORT
RF PORT
RF PORT
RF PORT
18a
18b
18c
18d
18e
18f
18g
18h
MU
MU
MU
20a
20b
20c

FIG. 1

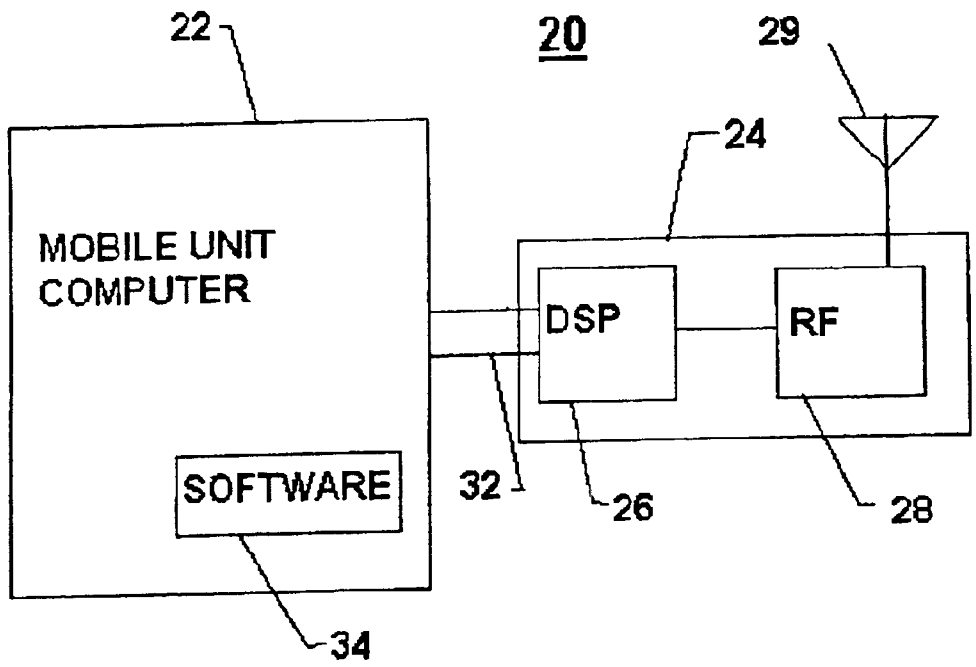


FIG. 2

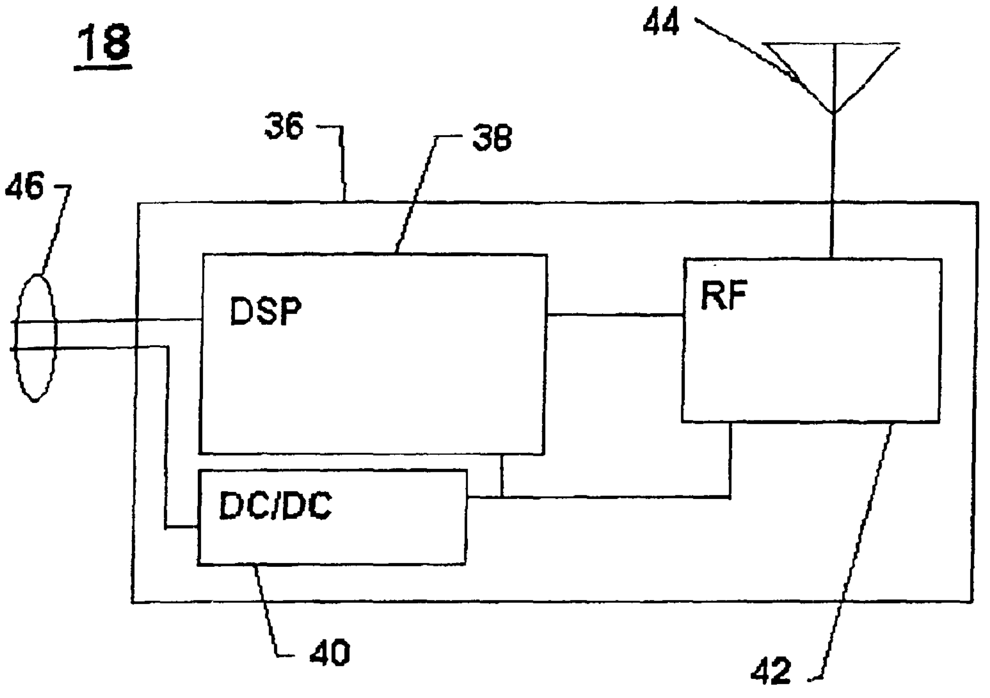


FIG.3

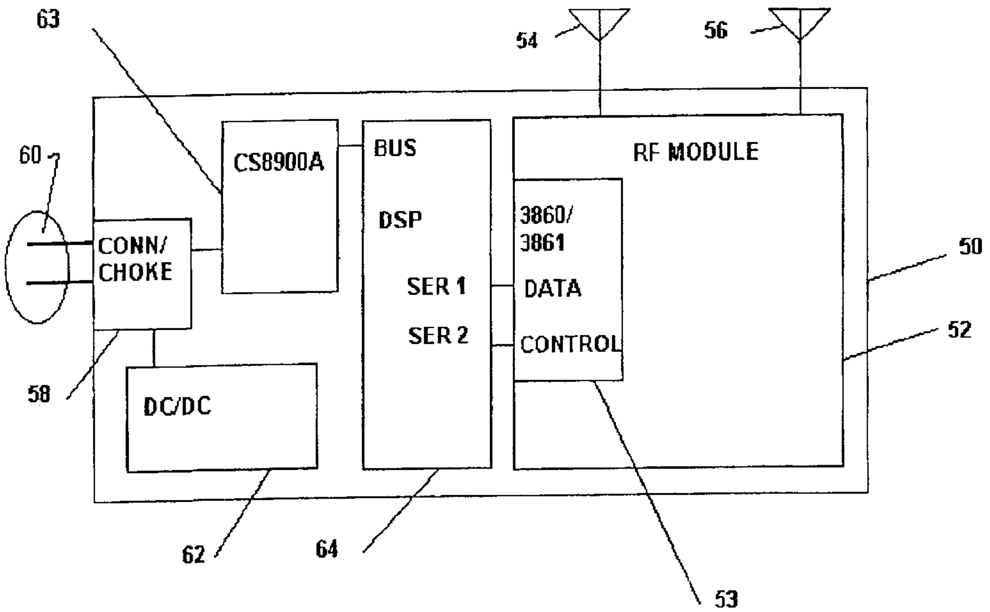

63
54
56
60
CS8900A
BUS
RF MODULE
DSP
3860/
3861
CONN/
CHOKE
SER 1
DATA
50
SER 2
CONTROL
52
58
DC/DC
62
64
53

FIG. 4

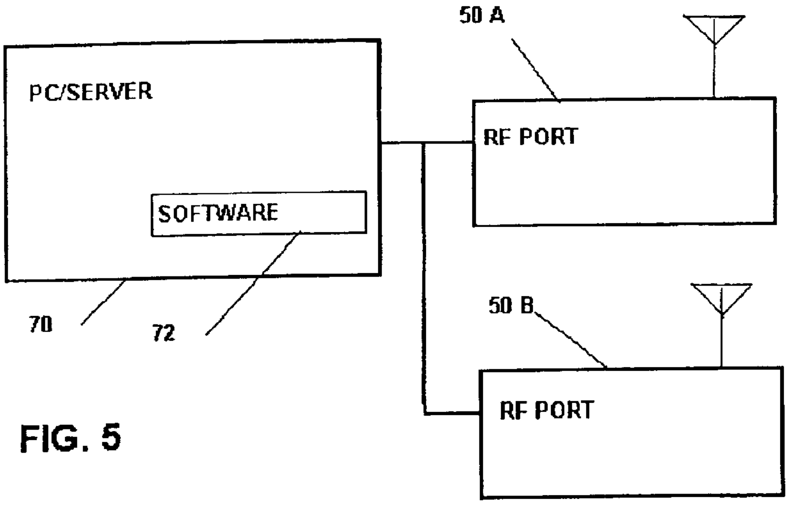

50 A
PC/SERVER
RF PORT
SOFTWARE
70
72
50 B
RF PORT

FIG. 5

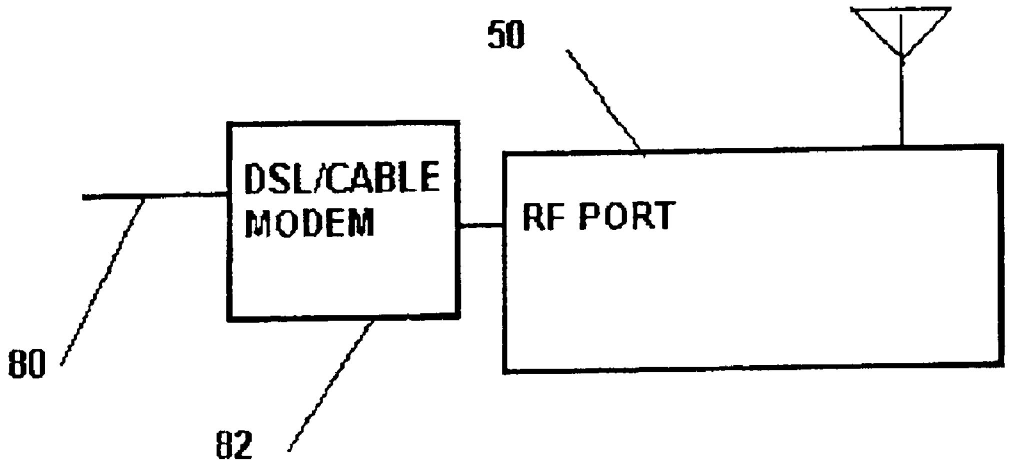
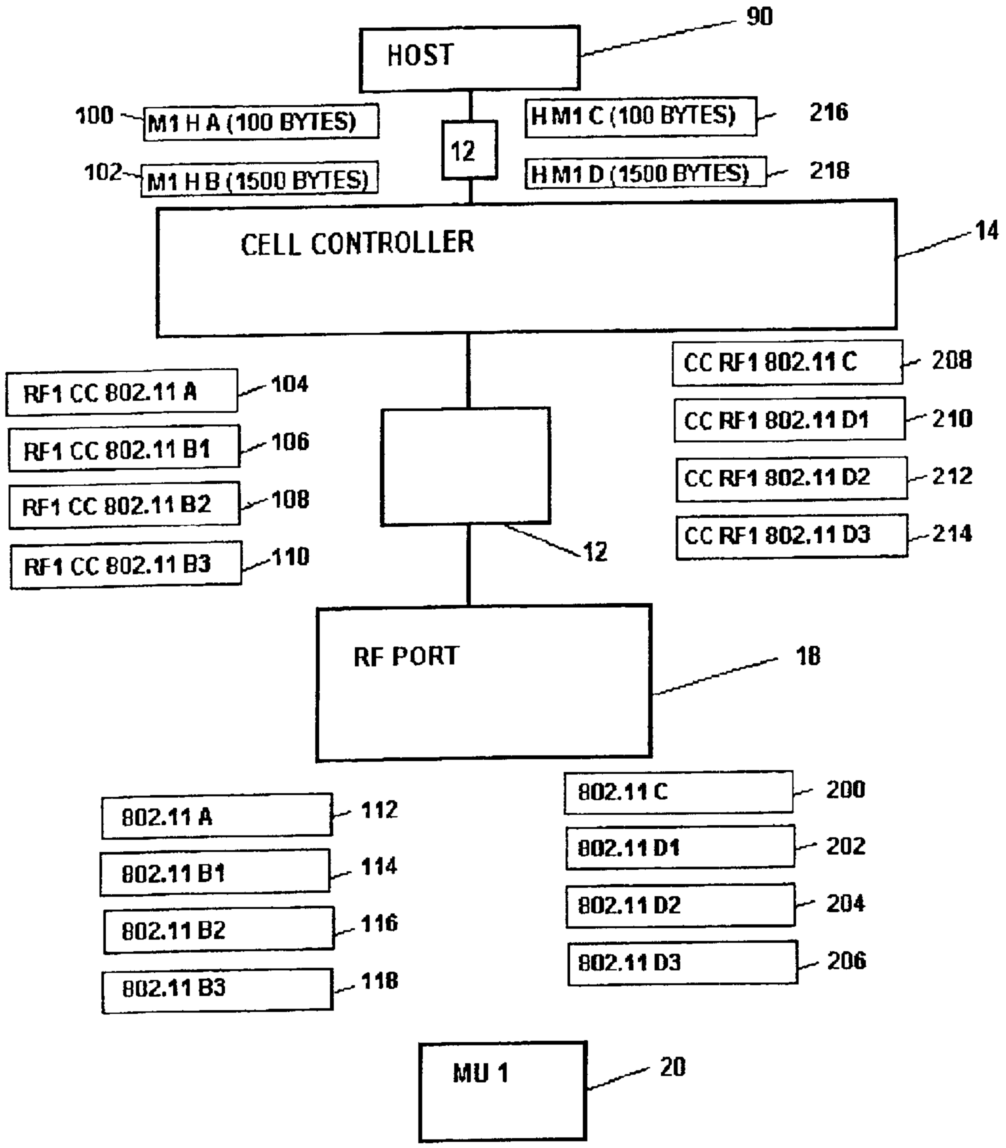


FIG.6



HOST
90
100
M1 H A (100 BYTES)
102
M1 H B (1500 BYTES)
12
H M1 C (100 BYTES)
216
H M1 D (1500 BYTES)
218
CELL CONTROLLER
14
RF1 CC 802.11 A
104
RF1 CC 802.11 B1
106
RF1 CC 802.11 B2
108
RF1 CC 802.11 B3
110
CC RF1 802.11 C
208
CC RF1 802.11 D1
210
CC RF1 802.11 D2
212
CC RF1 802.11 D3
214
12
RF PORT
18
802.11 A
112
802.11 B1
114
802.11 B2
116
802.11 B3
118
802.11 C
200
802.11 D1
202
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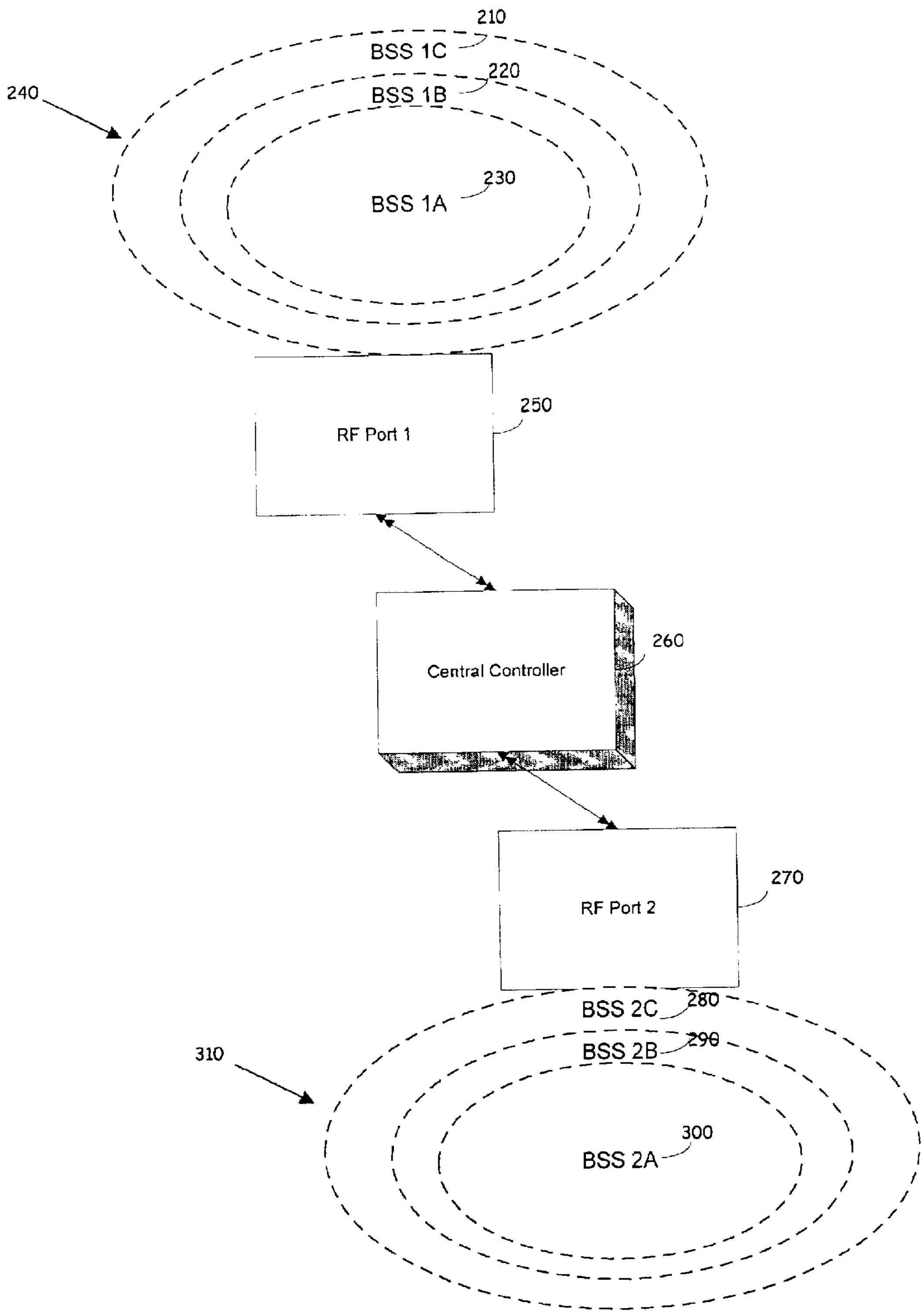
204
802.11 D3
206
MU 1
20

FIG. 7

FIG. 8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BSS 1C
220
BSS 1B
240
230
BSS 1A
250
RF Port 1
260
Central Controller
270
RF Port 2
BSS 2C
280
BSS 2B
290
310
300
BSS 2A

MULTIPLE WIRELESS LOCAL AREA NETWORKS OCCUPYING OVERLAPPING PHYSICAL SPACES

REFERENCE TO PRIOR APPLICATION

This application is a continuation-in-part of pending application Ser. No. 09/528,697, filed Mar. 17, 2000.

BACKGROUND OF INVENTION

This invention relates to wireless data communications networks, and in particular to arrangements for communications between mobile data handling units and a central computer using wireless data communications.

The assignee of the present invention supplies a wireless data communications system known as the Spectrum 24 System, which follows the radio data communications protocol of IEEE Standard 802.11. In the system as implemented, mobile units are in data communication with a central computer through access points. The access points may communicate with a central computer or computers over a wired network. Each of the mobile units associates itself with one of the access points. The access points in this system are functional to perform all the implemented requirements of the standard protocol, including, association and roaming functions, packet formulation and parsing, packet fragmentation and re-assembly encryption and system access control. In order to maintain order and reduce radio communications each access point must determine which of the data communications received over the wired network from the central computer is destined for a mobile unit associated with that particular access point. This requirement adds significant computational capacity to the access point, increasing the cost thereof.

In addition, in applications that must support a high volume of data communications from multiple users, such as systems supporting a self-service shopping system, hospital systems, systems that include paging or voice data links to many users, or systems supporting communicating with electronic shelf labels, additional access points are required to support the data communications traffic, increasing the overall system cost.

The cost of an operational access point is dependent not only on the complexity thereof and the requirement for high speed processing of data pockets for purposes of selecting those destined for mobile units associated with an access point, but the additional cost of the installation of electrical power to the location of the access point, and the cost of a power supply to convert AC electrical power to DC power for the circuits of the access point. Further cost may be involved in physically mounting the access point hardware and antenna.

In prior systems each access point is connected on an Ethernet wired network to the central computer. The access points are required to determine the identity of mobile units which have become associated with them and to extract from the data packets on the Ethernet network those packets addressed to a mobile unit associated with the access point. This requirement has led to significant processing burden for the access points and led to increased cost for the access points.

In the system described in my prior published International Patent Application WO 099 37047, published Jul. 22, 1999, the central computer communicates over an Ethernet wired network with an intelligent switching hub. Alternately a token ring network can be used. The switching hub

determines the destination of each packet and routes packets to an access point if the destination of the packet is a mobile unit associated with the access point. To achieve this function, the hub is an intelligent hub which maintains a routing list of mobile units and their associated access point according to the port of the hub.

In practice, the hub need only maintain a source list for those access points connected to the hub and mobile units associated with the access points connected to the hub. Thus, if a packet is received at a hub over the Ethernet with a destination address which is not associated with that hub, the packet is ignored. The hub will route the packet to an access point only if the destination address of the packet is identified on the list. When a packet is received on a hub port associated with a communications line connected to an access point, the source address is associated with the hub port in the list. The packet is routed either to the Ethernet connection or to another port according to the destination address.

By determining destination address in the hub and maintaining the association of a mobile unit address with an access point connected to a port of the hub in a routing list of the hub, the functionality required of the access points is greatly reduced. The access point acts merely as a conduit sending RF transmissions of packets received on its communication line, and receiving transmissions from associated mobile units and providing Ethernet packets to the hub. In addition, the access point must provide mobile unit association functions and other 802.11 protocol functions, as provided in the Spectrum 24 system, and may also provide proxy polling responses for associated mobile units that are in power saving mode.

The prior system may have a large number of access points, each with a memory containing program instructions for carrying out the various required functions. This distribution of processing makes it difficult to upgrade a system or to provide changes in system configuration because any upgrade or change may require changes to the program code in each of the access points. Such distribution of processing functions also makes system management functions, such as load balancing or access control more difficult.

It is therefore an object of the present invention to provide an improved wireless data communications methods and systems having lower cost, to enable the economical provision of reliable wireless data communications with increased capacity in complex installations or at reasonable cost or simple installations.

SUMMARY OF THE INVENTION

In accordance with the invention there is provided a system for providing wireless data communications between mobile units and a wired network. The system includes a plurality of RF ports having at least one data interface and arranged to receive formatted data signals at the data interface and transmit corresponding RF data signals and arranged to receive RF data signals and provide corresponding formatted data signal. There is also provided at least one cell controller, arranged to receive data signals from the wired network and to provide formatted data signals corresponding thereto and to receive formatted data signals and to provide data signals corresponding thereto to the wired network, the cell controller controls association of mobile units with one of the RF ports, provides formatted data signals for said mobile units to an associated RF port and receives formatted data signals from the mobile unit from the associated RF port.

In accordance with the invention there is provided an improvement in a wireless data communications network coupled to a data processing system, having a plurality of RF ports and mobile units, wherein the mobile units associate with one of the RF data communications ports to conduct data communications with said data processing system. The mobile units are assigned to one of the RF ports by a cell controller, and the cell controller is arranged to receive first data communications from the data processing system and to relay the data communications to an assigned RF port and to receive second data communications from the RF ports and relay the second data communications to the data processing system.

In accordance with the invention there is provided a method for operating a wireless local area network having at least one RF port, a plurality of mobile units and a cell controller coupled to the RF port. The RF is operated port to relay signals received from mobile units to the cell controller and to relay signals received from the cell controller to the mobile units. The cell controller is operated to control association of the mobile units with the RF port, including sending and receiving association signals between the RF port and the cell controller, and to send messages to and from the mobile unit via the RF ports.

In accordance with the invention there is provided an improvement in a mobile unit for use in a wireless data communications system, wherein the unit has a data processor and programs for the data processor and a wireless network adapter having a programmed processor and a radio module. The programmed processor performs first communications processor functions including control of the radio module and the data processor operates under the programs to perform second communications processor functions, including association with a radio access location of the wireless data communications system.

According to the invention there is provided an improvement in a wireless data communications system for providing data communications following a standardized protocol, wherein the protocol includes association of mobile units with radio access locations. At least one RF port is provided at a radio access location, which RF port comprises a radio module and an RF port processor in data communications with a programmed computer. The RF port processor performs first functions of the standardized protocol and the programmed computer performs second functions of the standardized protocol, including the association of mobile units with said radio access location.

According to the invention there is provided an RF port for use in a wireless data communications system comprising a radio module having a data interface and a transmitter/receiver for wireless data communications; and a digital signal processor having first and second data communications ports, random access memory and read-only memory. The second data communications port is coupled to the data interface of said radio module. The read-only memory is provided with a bootloader program for controlling the digital signal processor to load program instructions to the random access memory via the first communications port. According to the invention there is provided a method for operating an RF port having a radio module, a digital processor, random access memory and read-only memory. A bootloader program is stored in the read-only memory. The digital processor is operated to download instructions from a computer to the random access memory using the bootloader program and the RF port is operated under the downloaded instructions to send and receive messages using the radio module.

According to the invention there is provided a method for transmitting signals having a wireless signal format using an RF port having a wired network interface, a data processor and an RF module. Signals are provided to the wired network interface having wireless address data and message data within a data packet addressed to the RF port using a protocol for the wired network. The processor is operated to provide wireless data signals having the wireless signal format for the address data and the message data to said RF module and operating the RF module is operated to transmit the wireless data signals as an RF signal modulated with the wireless signal format.

According to the invention there is provided a method for transmitting signals having a wireless signal format using an RF port having an Ethernet interface, a data processor and an RF module. An Ethernet data packet is provided to the Ethernet interface, the Ethernet data packet encapsulating as data a data message having the wireless signal format. The data processor is operated to provide the data message to the RF module. The RF module is operated to transmit the data message as an RF signal.

According to the invention there is provided a method for receiving signals having a wireless signal format including wireless address data and message data at an RF port having a wired network interface, a data processor and an RF module. The RF module is operated to receive RF signals having the wireless signal format. The data processor is operated to receive wireless data signals from the RF module and provide data signals to the wired network interface comprising a data packet having a source address corresponding to the RF port using a protocol for the wired network, the data packet including the wireless address data and the message data.

According to the invention there is provided a method for receiving RF message signals having a wireless signal format including an address data format and message data using an RF port having an Ethernet interface, a data processor and an RF module. The RF message signals are received in the RF module and provided as data signals to the data processor. The data processor is operated to interpret address data in the data signals and, in dependence on the address data, said message data and said address data is encapsulated in an Ethernet packet, which is provided to the Ethernet interface.

In accordance with the invention there is provided a simplified wireless local area network system including a computer having a data processor and a memory, an RF port having an RF port data processor, an RF module and a data communications interface coupled to the computer. A first program is provided in the memory of the computer for operating the computer data processor to perform first wireless data communications functions, including association with mobile units. A second program is provided for operating the RF port data processor to perform second wireless data communications functions.

According to the invention there is provided a wireless access device for providing wireless access to a communication system. The device includes a modem for sending and receiving data messages on the communications system and an RF port, having a data interface coupled to the modem, a data processor and an RF module. The data is programmed to receive data messages from the modem, to format the messages for wireless data communications and to provide the formatted messages to the RF module for transmission by RF data signals to at least one remote station, and to receive RF data signals from the at least one remote station,

and to provide data messages to the modem to be sent on the communications system.

According to the invention there is provided a method for providing wireless access to the Internet. A modem having a data communications interface connected to an RF port is connected to the Internet. The RF port is configured for wireless data communication to at least one mobile unit having a predetermined wireless communications address. A mobile unit configured with the predetermined wireless communications address is provided for conducting RF data communications with the RF port. The RF port is arranged to relay communications between the mobile unit and the modem.

The apparatus and methods of the present invention provide RF ports as radio access locations which are less expensive than known access points and provide greater system management and flexibility. Much of the software used for controlling communications to and from mobile units is performed in a controller wherein software upgrades and changes are easily implemented. According to some embodiments, wherein instructions are downloaded to RF ports, it becomes easy to upgrade RF port instructions. System control is centralized, making management easier and enabling changes to access control and encryption functions. Priority for traffic purposes can also be established to facilitate digital telephony by giving priority to voice traffic. Accordingly, a system is provided that has significant flexibility using common RF port hardware to provide a wireless LAN having from one to hundreds of radio access locations.

According to the invention, the same RF port may provide multiple ESS identifications such that each ESS identification is associated with a separate virtual wireless local area network having its own policies and security.

For a better understanding of the present invention, together with other and further embodiments thereof, reference is made to the following description, taken in conjunction with the accompanying drawings, and its scope will be pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a wireless communications system in accordance with the present invention.

FIG. **2** is a block diagram illustrating one example of a mobile unit arranged to be used in the system of FIG. **1**.

FIG. **3** is a block diagram illustrating one example of an RF port for the system of FIG. **1**.

FIG. **4** is a more detailed block diagram of a preferred embodiment of an RF port in accordance with the invention.

FIG. **5** is a block diagram of an arrangement of a computer and RF port for providing a simplified wireless local area network according to the present invention.

FIG. **6** is a block diagram of an arrangement for providing wireless access to the Internet using the RF port of the present invention.

FIG. **7** is a diagram showing signal format according to one embodiment of the invention.

FIG. **8** is a diagram showing an compilation of RF ports having multiple ESS arrangements for providing overlapping, multiple wireless networks.

DESCRIPTION OF THE INVENTION

Referring to FIG. **1**, there is shown an example of a wireless data communications system **10** according to the present invention for providing data communications between a central computer or a collection of computers on a wired network **16** and a plurality of mobile units **20**. While prior systems used access points at each radio access location, where the access points are capable of managing wireless communications with mobile units, the system of FIG. **1** uses simplified RF ports **18** at each radio access location to provide radio packet communications with the mobile units **20** using a wireless communications protocol, such as IEEE Standard 802.11, whereby the radio modules in the mobile units **20** monitor polling signals from the RF ports **18**, which are originated by the cell controllers **14** and associate with an RF port **18** for purposes of data communications. The system arrangement of FIG. **1** is especially effective in a large wireless local area network (LAN) system wherein it may be necessary to provide a large number of radio access locations. Typically such systems, operating at low power microwave frequencies, require radio access locations at about every 100 feet. Where the wireless LAN system must operate with mobile units, for example, portable computers or similar devices, located throughout a large facility, such as a business, hospital complex or university campus, many such radio access locations may be required, possibly several hundred. Accordingly there is an incentive to reduce the cost of the installation at each radio access location. According to the present invention the system configuration and operation are redesigned to reduce the cost of each individual radio access point. In addition, the system of the present invention provides a concentration of operational control in one or more central controllers **14**, making management of the system easier and making modifications and upgrades easier to install.

According to the invention, much of the functionality of the 802.11 protocol associated with the conventional access point, is removed from the device located at the radio access location and provided in a cell controller **14**, which may be located in conjunction with a switching hub **12**, connected to the wired network **16**, with which the wireless network **10** is associated. In particular the usual "access point" device is replaced with a simpler device **18**, herein referred to as an "RF port" which contains the RF module, which may be the same RF module used in the prior art access point, and simplified digital circuits to perform only a limited portion of the 802.11 media access control (MAC) functions performed by the prior art access point. In particular the RF port **18** preferably performs only functions of the access point that require a lower level of processing resources in terms of processor capacity and software complexity (memory requirement), and which are time critical. Other functions that are more processor intensive and require more complex programming, and which are not time critical, are relegated to one or more "cell controllers" **14**, which may perform these more complex functions for a plurality of RF ports **18**.

In order to perform the higher level processing functions of the access point in the cell controller **14**, according to the present invention, all messages directed to or from mobile units **20** associated with a particular RF port **18** are processed in a cell controller **14**. A system may have one or more cell controllers, which may comprise, e.g. Pentium-type board level computers, each of which is arranged and programmed to handle data message traffic and mobile unit associations for a selected plurality of RF ports **18**. A switching hub **12** may be interposed to provide message switching among the wired network connected to communications line **16**, RF ports **18** and cell controllers **14**. Each of the one or more cell controllers **14** acts as a virtual "access

point" for traffic addressed to its associated RF ports **18** and to the mobile units **20** associated with those RF ports. When a message is addressed to a mobile unit **20** is received on line **16**, switching hub **12** directs the message to the appropriate cell controller **14**, which reformats the message and relays the message to the appropriate RF port **18**, again through switching hub **12**. When the message is received by an RF port **18**, it is converted to a radio message and sent to the mobile unit **20** with a minimum of processing.

Likewise, when a message is received from a mobile unit **20** by an RF port **18**, it is converted to a digital message packet and relayed to the cell controller **14** associated with the RF port **18** through the switching hub **12**. The cell controller **14** parses the message for further relay in the system.

An important feature of a preferred embodiment of the invention is the fact that mobile unit association with the RF ports **18** is a function handled by the cell controller **14**. Accordingly, when a mobile unit **20** first becomes active, it sends an association request signal in response to a beacon signal sent by an RF port **18** (in response to direction by the cell controller). The association request signal is relayed by the RF port **18** to the cell controller **14**, which performs the processing required for association, including consideration of RF port loading. Cell controller **14** generates appropriate response signals to be sent by the RF port **18** to the mobile unit **20**. The cell controller **14** is in an appropriate position to evaluate the loading of the RF ports **18** under its control, and may therefore easily perform load leveling functions, for example, by providing a message to RF port **18** accepting or declining an association request. In addition, the cell controller **14** may receive load messages from other cell controllers **14** in the system **10** and thereby coordinate overall load management. As a mobile unit **20** moves from a location serviced by one RF port **18** to a location serviced by a different RF port **18**, the cell controller **14** receives information from the mobile unit **20** indicative of its reception of beacon signals from the various RF ports in the system and performs the necessary functions to support roaming of mobile unit **20**.

While in the system **10** of FIG. **1** the cell controllers **14** are shown as separate computers connected to switching hub **12**, the term "cell controller" is intended to refer to the logical functions performed by these computers rather than the computers themselves. As will become apparent, the cell controller may be implemented in a variety of ways other than as shown in the exemplary system **10** of FIG. **1**.

Implementation of a simplified RF port is achieved by performing "higher level" functions of the 802.11 protocol Media Access Control (MAC) in the cell controller and performing "lower level" functions in a simplified RF port.

The lower level functions are those that are hardware intensive and often time critical. The higher level functions are those that are software intensive and not time critical. One possible division of the exemplary 802.11 MAC functions is as follows:

Lower Level Functions (preferably to be performed at RF port)

Cyclic Redundancy Check (CRC)

Network Activity Vector (NAV)

Ready to Send/Clear to Send (RTS/CTS)

Header generation/parsing

Collision Avoidance

Frequency Hopping

Ack parsing/generating

Retransmission timeout

Higher Level Functions (preferably to be performed at Cell Controller)

Association processing

Roaming

Retransmission

Rate Control

Host Interface

The following optional (higher or lower) level MAC functions can be placed in either the higher or lower level categories.

Wired Equivalent Privacy encryption/decryption (WEP)

Fragmentation/Reassembly

Data Movement

Power Save Polling Support (PSP)

According to a preferred arrangement of the system of the invention, the lower level MAC functions are provided at the RF port, the higher level MAC functions are provided in the cell controller and the optional level functions can be provided at either the cell controller or the RF port.

A major advantage of the invention is a cost savings in hardware, processor capacity and storage capacity for the RF port. Since a system with, for example, one hundred or more radio access locations may be implemented with one or two cell controllers, the processor hardware and memory required for the higher level MAC functions need be provided only at the cell controllers. In fact, the capabilities of the overall system, for WEP encryption and other special functions, can be increased at modest cost by using a high performance board level personal computer or even a host computer as a cell controller.

By eliminating the higher level MAC functions from the radio access locations, the cost of the devices installed at those locations can be significantly reduced because of lower processor capacity and storage.

In connection with association and roaming functions the RF ports **18** provide beacon signals in response to commands generated by the cell controller **14**. When an association sequence is initiated by a mobile unit, the RF port **18** relays the association messages between the mobile unit **20** and the cell controller **14** during the association process, which is handled by the cell controller **14**.

In connection with message traffic to a mobile unit **20** from a network processor, message packets are routed by switching hub **12** to the cell controller **14** responsible for the mobile unit **20** addressed. The message is buffered and formatted by the cell controller **14** and in a preferred arrangement encapsulated by the cell controller **14** as a mobile unit packet within a wired network packet addressed to the responsible RF port **18**. This packet is routed to the RF port **18**. The RF port **18** extracts the mobile unit packet from the message and sends the packet to mobile unit **20** as a radio signal. The RF port **14** may also provide a CRC calculation and generate CRC data to be added to the message. The mobile unit **20** responds with an acknowledgment signal to the RF port **18**, which generates and sends an acknowledgment status message to cell controller **14**.

In connection with messages for systems connected to the wired network **16**, the mobile unit **20** sends a packet to the RF port **18** by radio signal. The RF port **18** filters received radio message packets according to the BSS (Basic Service Set) identifier in the packet and, if the packet has a BSS identifier associated with the RF port **18**, performs the CRC check as the packet is received. The RF port **14** then

generates and sends an acknowledgment signal to the mobile unit **20** and sends the received packet to cell controller **14**. Cell controller **14** buffers, parses and, if necessary, decrypts the packet and routes the packet to the host on network **16** through hub **12**.

The arrangement of RF port **18** may be identical to current access points used in the Spectrum 24 system with some of the access point software non-functional. Preferably the RF ports are simplified to reduce cost and power consumption. To reduce installation expenses the RF ports are powered via an Ethernet cable, which also connects RF ports **18** to switching hub **12** or to cell controller **14**. The RF ports can be arranged in a small package (e.g. portable radio size) with integrated diversity antennas and arranged for easy mounting, such as by adhesive tape or Velcro. Connection to the switching hub **12** is by Ethernet cable which is also provided with D.C. power, such as by use of a choke circuit, such as Pulse Model PO421 as described in my referenced International Application. The choke circuit may be built into an Ethernet connector and is available in this configuration.

The RF port **18** does not have to perform Ethernet address filtering and does not have to perform 802.11 association and roaming functions and can therefore have a lower level of processor capacity, software support, memory and power consumption. In one embodiment shown in FIG. **3** the RF port **18** includes only a digital signal processor (DSP) **38** which includes internal RAM and ROM. The DSP **38**, which may be one of the Texas Instruments TMS 320 family of DSP processor, such as the 5000 series, specifically the TMS 320 UC 5402 or the TMS 320 VC 5402. This DSP provides an interface between the Ethernet cable **46** and the RF module **42** in RF port **18**, as shown in FIG. **3**. The RF module **42** is provided in housing **36** with DSP **38**, DC/DC power supply **40** and carrying one or more antennas **44**. RF module **42** includes a 3860 or 3861 baseband processor, such as HFA 3860B, to interface with the digital portion of the RF port **18**, specifically DPS **38**. In one arrangement the ROM memory of the DSP **38** can be provided with "bootloader" firmware that downloads the necessary DSP software instructions from the cell controller **14** upon startup of the RF port **18**, and loads the instruction into the RAM of the DSP **38**.

The processors that are currently preferred as a possible lower level MAC engine are the TMS320UC5402 and the TMS320VC5402. These parts are functionally identical except for differences in power consumption (the VC5402 is currently in production and while the UC5402 is still being sampled). The basic configuration of the UC5402/VC5402 is:

100 MIPS execution rate
8 KB on chip ROM (organized as 4K×16 bits)
32 KB on chip RAM (organized as 16K×16 bits)
Two 16 bit timers with 1 µs or better resolution
Two High speed, full duplex serial ports (up to 50 Mbits/sec each) with smart DMA channel support
One High speed 8 bit wide host/parallel port (160 Mbit/sec)
Six DMA channels for general purpose use
16 bit external memory/IO Bus with internal wait state generation
16 interrupts with 3 instruction (30 ns) worst case latency
0.54 mW/MHz power consumption (30 mA@1.8 v at 100 MHz)
Low Power Modes (6 mA, 2 mA, 2 µA depending on setting)
Internal PLL that generates the system clock with an external crystal

This section will describe the use of a 5402 DSP **38** as a MAC engine for 11 Mbit/sec 802.11 DS systems. It could clearly be used in FH systems as well. We will focus on the how the 5402 interfaces to the Intersil 3860/1 baseband processor in RF module **42** and how it implements the lower level MAC functions.

The first issue is how the 5402 DSP **38** interfaces to the 3861 (much of what is said applies to the 3860 as well) and the rest of the RF module **42**. As shown in FIG. **4**, the 3861 processor **53** in RF module **52** of RF port **50** has 2 major interfaces, both serial. The first interface, labeled DATA, is used to transfer data between the MAC engine comprising DSP **64** and the 3861. It has four lines: T×D, T×C, R×D, and R×C and operates at up to 11 Mbits/sec. The exact rate depends on the transfer rate of the packet. The clock signals of both interfaces are generated by the 3861 and so transfers are controlled by the 3861. Both can be halted at any time by the 3861 as well as change rate. The second serial interface, labeled CONTROL is used to load commands into the 3861 and read status information from the 3861. This interface is a 4 wire bi-directional interface using one data line, one clock line, one "direction control" line, and a chip select line. This serial interface also can operate at up to 11 Mbits/sec. In addition to the serial interfaces, there are additional control and status lines such as Reset, TX_PE, RX_PE, TX_RDY, etc.

The 5402 DSP **38** has two sets of full duplex serial interfaces that are capable of operation up to 50 Mbits/sec (given a 100 MHz clock). They can be clocked using internal or external sources. In this design one of the sets of serial interfaces, labeled SER**1**, is used to connect to the high speed data lines of the 3861 interface **53**. The 5402 DSP **38** interfaces have the same basic lines (R×D, R×C, T×D, T×C) as does the 3861 and so they connect with minimal trouble. Although the 5402 uses 1.8 v for its core, its I/O lines are 3.3 v tolerant and so can interface to the 3861 without converters. In addition, they are fully static and so can deal the start/stop operation of the clock lines from the 3861.

Data transfer will be done under DMA control within the 5402 using what TI calls "Auto Buffering Mode." This provides essentially dedicated DMA channels for each serial port interface (two DMA channels per serial port interface). These channels access an independently operating bank of SRAM and so transfers have no impact on CPU performance. The CPU can start transfers in either direction and be notified via interrupt on their completion.

Interfacing to the control serial port on the 3861 interface **53** can be done in three different ways. The first, illustrated in FIG. **4**, utilizes the second serial port, labeled SER **2** on the 5402 DSP **64** with a small amount of combinatorial logic/buffering to convert between the single data line of the 3861 and the dual data lines of the 5402. Another approach is to use an external shift register that would perform serial/parallel conversion. This register would sit on the I/O bus of the 5402 and would be loaded/read by the 5402 and data shifted between it and the 3861. The third approach is to use an external buffer/latch on the 5402 I/O bus and "bit bang" the clock/data lines to the 3861. The second or third approaches free up the second serial channel for more other use such as providing high speed serial interfaces such as Ethernet or USB and in some applications would be preferred over the first. All require a small amount of external combinatorial logic and so the cost of all solutions is about the same.

The same logic would apply to interfacing to the synthesizer. It is accessed even less often than the control port of the 3861 and so a "bit banging" approach would work fine.

Finally, interfacing to the various control and status lines presented by the 3861 can be done via simple bi-directional

register/latch connected to the I/O bus of the 5402. The 5402 can read/write this register as it needs to control and monitor the 3861. It would be possible to combine all control/monitor functions (including the serial control interface) into a single 16 bit buffered register latch. Parallel control/status lines would be connected to particular lines of this latch. Serial control interfaces would also be connected and "bit banged" as necessary to move data between the 5402 and 3861.

The arrangement shown in FIG. **4** uses a Crystal CS 8900 A Ethernet controller **63** coupled to the parallel port of DSP **64** to interface to the Ethernet port **58**. An Ethernet connector/choke **58** receives cable **60** and provides DC power from cable **60** to DC/DC power supply **62**. The FIG. **4** RF port **50** includes spaced diversity antennas **54**, **56** to improve reception in multipath conditions.

A premise of this design is that the TI DSP is capable of implementing all lower level MAC functions without external hardware assistance. This, of course, is the most demanding model but we will find that the 5402 is up to the task. The most computational demanding tasks are the CRC-32 and WEP processing. The CRC-32 calculation is performed over the entire packet and must be completed in time to generate an ACK should the CRC turn out to be correct (or to attach the calculation result to an outgoing packet on transmission). This means that the CRC calculation must be performed in near real-time during packet transfer between the 3861 and 5402. TI has shown in an application note that a CRC-32 calculation can be made by a 5000 series DSP in 13 instructions. At 100 MIPS this is about 130 ns. At 11 Mbit/sec, a byte takes about 770 ns to transfer and so we have plenty of time to do the CRC. When receiving a packet, the serial port would be transferring the data from the 3861 to SRAM within the 5402. At the same time the CPU within the 5402 would be reading each received byte from SRAM and calculating the CRC. It would of course have to make sure that it did not overrun the receive buffer, but that would be a relatively simple task. Much the same process would happen during transmission. In either case, the CPU has lots of time to do the CRC.

The WEP processing if performed in the RF port **50**, is a harder function to perform than CRC-32 since it includes both an RC4 encryption function and a second CRC-32. At the same time it does not need to be completed prior to ACK generation/reception nor is performed on every packet (just data packets). The RC4 encryption function consists of two parts: building the encryption table (a 256 byte table) using the selected key and doing the encryption/decryption process. Based on sample code, it is estimated that building the table would require about 1200 instructions (12 ms at 100 MIPS) and the encryption/decryption process would require about 12 instructions/byte. There is no difference in this cost for 40 or 128 bit keys. The WEP CRC-32 would require another 13 instructions per byte.

The per byte computational burden for WEP would thus be about 25 instructions or about 250 ns at 100 MIPS. When added to the packet CRC-32, the total load would be around 38 instructions/byte. As we pointed out, at 11 Mbit/sec we have about 77 instructions/byte available, so we are spending about 50% of the CPU on CRC/WEP tasks. The biggest issue is the 1200 clocks (12 us) required to build the encryption table during receive (For transmission, the calculation can be done prior to starting packet transfer). Pausing to create the table would put the CPU about 18 bytes (12 us at 770 ns/byte) behind in the CRC/WEP/CRC calculation process. It would require about 40 data bytes to catch up (1200 clocks/30 extra clocks per byte) in both packet CRC and WEP/CRC functions. Since the minimum TCP/IP header is at least 40 bytes (plus any user data), we should have enough time. In any case if we are a little late in WEP/CRC calculation, no harm is done. An alternative approach would be to catch up first for the packet CRC calculation and then catch up with WEP/CRC.

After CRC and WEP/CRC processing, the next most critical activity is header parsing on receive and generation on transmit. This is because of the need to identify packets for the station and generate appropriate responses. On receive, the processor must parse two or three 48 bit addresses and at least a 16 bit header command field. After the packet completes, an ACK may need to be generated.

The 5402 can easily handle these functions. Since these functions are performed prior to WEP processing, the CPU has 64 instructions/byte (77–13) to perform these functions. Since many of them can be performed on a 16 bit or even 32 bit basis (the 5402 supports both 16 and 32 operations), there may be up to 128 or 256 instructions per data item (i.e. 256 instructions to perform a 32 bit address check). These functions are performed at 2 Mbit using a 1 MIPS 188 CPU. We have a 100 MIPS CPU to do the same tasks at 11 Mbit/sec.

ACK generation is likewise relatively simple. An ACK frame is only 14 bytes long, including the 4 CRC-32. Given there is a long (80 us) preamble, we have 8000 instructions to prepare the ACK. The same applies to RTS/CTS exchanges.

There are two 16 bit timers available on the 5402. In this model, one would be used for TSF timing and the other for all other functions. There are really only a few other timer functions: NAV, Retransmission, collision avoidance slot countdown, etc. Retransmission and collision avoidance activities go on only when waiting for an ACK or to start a retransmission after detection of an idle network. In such cases there is no data transfer going on and so there is lots of CPU cycles available.

Support for MU PSP function can be done in a variety of ways, depending on how much, if any, external hardware is provided. The 5402 provides a variety of means of conserving power. The first is simply to slow down the CPU clock via the software controlled PLL within the unit. The 5402 generates internal clocks via a PLL that is driven by either an external crystal or clock. The PLL multiplies the base frequency of the crystal/external clock by a factor determined by software. Hence one means of controlling power consumption is simply to slow down the CPU clock. Since the CPU portion of the processor consumes most of the power, slowing it down has the biggest affect on power consumption.

The second approach is use one of the IDLE modes of the processor. IDLE1 stops the CPU clock entirely but leaves everything else running. Power consumption in this mode is on the order of 6 mA at 100 MHz. The CPU can be restarted by any interrupt (internal or external). In IDLE2 the system clock is stopped and this reduces consumption to 2 mA. In IDLE3, all system functions are stopped and consumption is reduced to around 2 ua. In all cases all state is retained. In IDLE2 and IDLE3, an external interrupt is required to restart the CPU. In such cases an external, low power timer would be required.

Thus with no external hardware, power consumption could be reduced to at least 6 mA and perhaps less. With a simple external timer, one could get down to microamps.

The bottom line is that the vast CPU power of the 5402 allows all lower level MAC functions to be performed in software. Furthermore it has sufficient power and memory to

handle additional "higher level" functions such as packet retransmission, fragmentation, and reassembly that can also be done in a cell controller.

The system **10** of the present invention is compatible with IEEE Standard 820.11 and accordingly will operate with any mobile units **20**, including existing units, which are compatible with the same standard. However, the improvements applied to the RF ports **18**, reducing the complexity and cost of these units can also be applied to the mobile units **20**, which have sufficient main processor capacity to handle the mobile unit functions corresponding to the higher order MAC functions.

Referring to FIG. **2** there is shown a block diagram for a mobile unit **20** having a mobile unit computer **22** and a WLAN adapter **24** connected thereto to provide wireless communications to the system **10** of FIG. **1**. In the mobile unit **20** of FIG. **2**, the lower level MAC functions are performed in WLAN adapter **24**, which also includes RF module **28** and antenna **29**. The configuration of WLAN adapter **24** may be similar to existing adaptors, but preferably adapter **24** is simplified to perform only the lower level MAC functions of the IEEE 802.11 protocol and allow special software **34** in host computer **22** to perform the higher level MAC functions, such as association and roaming. In a preferred arrangement the MAC functions of adapter **24** are performed in a digital signal processor **26**, as described below, which may be the same type DSP described with respect to RF port **50**.

This section addresses how the 5402 DSP could be used as a MAC engine in Mobile Unit configurations. There are two considerations in building MU WLAN solutions. The first is the location of those MAC functions, while the second is the physical interface to the host.

The location of the upper level MAC functions may vary considerably. Some possibilities are:

All functions on MAC engine DSP processor **26**

All functions on host processor **22**

Roaming/association on host processor **22**, rest on MAC engine **26**

Roaming/association/retransmission on host **22**, rest on MAC engine **26**. The choice of the location of the higher level MAC functions has a major impact on the cost of MU WLAN adapter. If one is willing to place at least some of the higher level functions on a host processor **22**, then one could get by with just the 5402 on the WLAN adapter. Possible functions to place on the host would be roaming and association control. Higher level functions such as retransmission and fragmentation/reassembly could be left on the 5402. This split would permit significant savings, since another processor/memory subsystem would not be needed on the WLAN adapter. There are two reasons for not placing all of the MAC functions on the 5402. The first is memory space on the 5402 is only 32 KB of SRAM for both code and data. In some MAC implementations such as frequency hop, the code space alone exceeds 32 KB. The second reason is that the software on the 5402 is oriented toward meeting hard, real-time tasks such as CRC and WEP processing. Trying to add software intensive tasks would only complicate the process.

If another processor was required, such as an ARM or perhaps a second 5000 Series processor, the upper level functions could be added to it.

Alternatively one could place all the MAC functions on a faster and/or bigger version of the 5402 processor. Such a processor would likely have a higher clock rate (current members of the 5000 Series can be clocked as high as 160 MIPS) and more memory (say 64 KB instead of 32 KB).

Both the second processor as well as a faster/bigger 5402 would consume additional power as well as adding cost.

This section will describe one approach of how a MU WLAN adapter can be arranged for various hardware host interfaces using the 5402. It assumes that enough of the upper level MAC functions have been offloaded to a host processor so that only the 5402 is required on the PLAN adapter. A second processor could be added to any of the solutions outlined below.

In all of the following solutions, it is assumed that the runtime code for the 5402 is loaded from an external source (such as computer **22**) via the host interface **32**. This eliminates the need for flash memory on the adapter card, saving several dollars in the process. It should be pointed out that the 5402 comes with 8 KB of mask programmable ROM and a bootloader program (required for the USB and Ethernet host interfaces) would be placed in it. The bootloader would be smart enough to download the runtime code instructions over whatever serial interface was available.

The simplest interface of all would be for a host to use the Host Port on the 5402. This port operates as a dual port interface into the memory within the 5402. It would not be a standard interface but would be quite suitable for dedicated systems. Using it, computer **22** can read/write memory on a random or sequential basis. It is an 8 bit interface and can operate as fast as 160 Mbit/sec. When operated in random access mode, the computer **22** generates a 16 bit address using two writes to the port and then performs either a read or write operation. Such a mode allows a host to set up command blocks and the like within the memory of the 5402. Sequential mode allows a host to transfer data in and out of the 5402 memory very quickly (160 Mbit/sec). This would be used for transferring data.

If this approach was used, the only digital component on the WLAN adapter would be the 5402.

In the system of FIG. **1**, the cell controller **14** is a board level personal computer coupled to the switching hub **12** preferably by 10 M bit and 100 Mb Ethernet ports. For smaller systems a 350 MHz Pentium computer with 16 MB RAM may be used. For larger systems having many RF ports a 500 MHz Pentium with 64MB RAM is appropriate. Communications to and from the wired network are preferably carried out at 100 MHz. Communications to and from RF ports may be carried out at 10 MHz. A second cell controller may be supplied for larger systems and/or to provide backup in the event one cell controller fails. Reliability can be enhanced by providing dual fans and dual power supplies. A flash disk memory may be used for reliability. Alternately, the cell controller **14** may be built into the switching hub **12** or into a host processor.

The operating system for the cell controller **14** may be a real time operating system, such as VRTX or QNX, which provides multitasking, a full network stack and utilities. Web based management utilities, which are client side java based, are provided for maintaining the configuration of the cell controller **14**, the RF ports **18** and status of the mobile units **20**.

The cell controller **14** includes applications to provide mobile unit association management, roaming and packet buffer management. These applications are similar to those performed by current access points in the Spectrum 24 system. The cell controller **14** may also provide QoS support, user authorization and configuration management. Placing these functions on a personal computer cell controller facilitates system management and program updates using available programming tools. Further, modifications to authorization or management functions need only be

installed into the cell controller **14**, and no modification to the software of the RF ports **18** is required.

The cell controllers **14** handle routing of all messages to or from the mobile unit. The cell controller buffers message packets received from the wired network and determines the appropriate RF port **18** with which the addressed mobile unit **20** is associated and sends the packet to the RF port **18**. The cell controller **14** can additionally perform WEP encryption/decryption and the CAC associated therewith.

The cell controller **14** may also the additional function of maintaining and downloading firmware to the RF ports **18**. Upon power up the RF ports **18** use a bootloader routine stored in ROM to send a download request to cell controller **14**. The cell controller then downloads firmware to the RF port **18**, including configuration information such as channel assignment, ESS and BSS identification. The cell controller **14** and RF ports **18** additionally share a common TSF clock.

The mobile unit computer **22** of mobile unit **20** is provided with similar software to perform the higher level MAC functions as outlined above. Advantageously, the software **34** can be programmed using the same operating system as provided for the computer, and thereby provide a user interface, such as Windows, which is familiar to the user. The mobile unit software **34** provides the MAC functions of header building, roaming and association. The mobile unit computer **22** may also download firmware to the processor in the WLAN adapter **24**.

As evident from the forgoing description, the hardware for RF port **18** and WLAN adapter **24** of mobile unit **20** can be substantially similar, with the possible exception of the interface to an Ethernet network or to a mobile unit host. Further, the logical cell controller function and the higher order MAC functions performed by the mobile unit host processor can be performed on any computer system.

Using the RF port **18** of the present invention coupled to a computer system, it is possible to provide either a mobile unit or a wireless network according to the software provided. Since the software for RF port **18** may be downloaded from a host system a simple combination of a computer and one or more RF ports can function as either a WLAN mobile unit as a WLAN host or both, by providing function selectable firmware to the processor in the RF port.

In the arrangement shown in FIG. **5**, a personal computer **70** is provided with software **72** and connected to one or more RF ports **50**A, **50**B to provide a complete host system for wireless data communications. This arrangement could be used, for example, in a small business wherein office equipment is connected to server **70** by a wired network for conventional LAN operation and one or more RF ports **50** are also connected to server **70** on the LAN system to provide data communications between the server **70** and mobile units. The server can perform the higher order MAC functions and download firmware instructions to the RF ports. Alternatively, the firmware instructions can be installed on PROM memory in the RF ports.

FIG. **6** shows an arrangement for providing wireless access to the Internet using the RF port **50** of the present invention. Internet access over communications line **80** to modem **82** may be provided by cable, DSL or fiber optical transmission. RF port **50** may be provided with MAC firmware on PROM or may be configured with a bootloader program to download firmware from an ISP server. When installed in a home or office, mobile units **20** can associate with RF port **50** to initiate Internet access. The ISP server may perform the higher level MAC function, or they may be provided in RF port **50**.

The mobile units **20** may be the personal computers **22** in a home or office with a WLAN adapter **24** as shown in FIG. **2**.

FIG. **7** illustrates an example of communications formats that might be used in the various system embodiments of the present invention. The FIG. **7** example assumes that the configuration includes a host **90** connected to a dedicated cell controller **14**, which is likewise connected to RF port **18**. It should be clearly understood that the logical cell controller functions may be performed in host **90**, particularly in a simple system.

In the FIG. **7** example host **90** sends message "A" having 100 data bytes via an Ethernet packet **100** to cell controller **14**. Packet **100** has a destination address of the Mobile unit (M**1**), a source address of the host (H) and includes data (A). Cell controller **14** formats the data in 802.11 format with the destination corresponding to mobile unit (MU**1**) **20**. The cell encapsulates this 802.11 packet with data A into an Ethernet packet **104** addressed to RF port **1** (RF**1**) from the cell controller (CC).

RF port **18** receives the Ethernet packet **104** from cell controller **14** and generates and sends an RF packet **112** in 802.11 format to mobile unit **20**, including data A. It should be understood that 802.11 header generation can be provided at either the cell controller **14** or the RF port **18**, but packet **104** must include mobile unit identification data either as an 802.11 header or otherwise to enable RF port **18** to generate the header. RF port **18** additionally performs the CRC computation and adds the result to the 802.11 packet **112**.

A second message "B" having 1500 bytes of data is also shown as originating as Ethernet packet **102** from host **90** to cell controller **14**. Cell controller fragments data message B into three fragments B**1**, B**2** and B**3** to accommodate the 500 byte data limit of 802.11 packets. These three fragments are sent as Ethernet packets **106**, **108**, **110** to RF port **18**, which transmits RF signal packets **114**, **116**, **118** to mobile unit **20**.

Reverse communication is similar. Message C has 100 bytes and is sent by mobile unit **20** to RF port **18** as 802.11 RF signal packet **200**. RF port **18** encapsulates this message into Ethernet packet **208** and sends it to cell controller **14**, which extracts the destination information and data to provide Ethernet message **216** to the host **90**. A larger message D is sent as message fragments **202**, **204**, **206** to RF ports **18**, relayed as Ethernet packets **210**, **212**, **214** to cell controller **14** and sent as a reassembled Ethernet packet **218** to host **90**.

Referring now to FIG. **8**, shown is an application of the central controller/RF port model that may be used to set multiple overlapping ESS LANs for use in the same or overlapping physical space. Shown in FIG. **8** is a central controller **260** which is associated with two RF ports, RF port **1 250** and RF port **2 270**. The central controller **260** may be associated with more than two RF ports, but two are shown for illustration purposes. Each RF port **250**, **270** provides coverage for a wireless LAN in the physical areas **240**, **310**.

FIG. **8** further illustrates the concept of providing multiple ESS identifications through the same RF port and cell controller such that each ESS identification is associated with a separate virtual wireless local area network having its own policies and security. Thus, RF port **1 250** may be configured so as to support separate BSS networks **1**A **230**, **1**B **220** and **1**C **210**, all of which occupy the same physical space **240**. The RF port may support more than three BSS networks, but three are shown for illustration purposes. Similarly, RF port **2 270** may be configured so as to support BSS networks **2**A **300**, **2**B **290** and **2**C **280** all of which occupy the same physical space **310**. Using the configuration as shown in FIG. **8**, multiple ESS LANs may be coordinated by the central controller **260** in the physical space **240** and **310**. ESS A consists of BSS **1**A **230** and BSS

2A **300**. ESS B consists of BSS **1**B **220** and **2**B **290**. ESS C consists of BSS **1**C **210** and **2**C **280**.

As discussed in further detail above the RF ports **250**, **270** preferably performs only functions of the access point that require a lower level of processing resources in terms of processor capacity and software complexity (memory requirement), and which are time critical. Other functions that are more processor intensive and require more complex programming, and which are not time critical, are relegated to one or more cell controllers **260**, which may perform these more complex functions for a plurality of RF ports **250**, **270**. In the case illustrated in FIG. **8**, the central controller handles the necessary processing of multiple ESS LANs A, B, C in the same physical space **240** and **310**.

One application of multiple ESS LANs may be found on a public place, such as an airport where, for example, three levels of wireless networks may operate. A first public network level with generally open access to a wireless local area network that might provide, for example, public wireless telephone or internet access. A second network level would involve airport operations, such as luggage handling, aircraft servicing, etc. A third network level may be reserved for emergencies and security. Devices using the network can be restricted by the cell controller as to which virtual network they can access using the same RF port of the wireless network system. The cell controller would thereby control communications between mobile units accessing an RF port and the three or more virtual networks such that, for example, a member of the public using a publicly available device could only access the public functions of the system and therefore only have access to the lowest level of virtual wireless network. Other personnel, such as airport employees, may have access to the public level and also have access to the airport operational network. The security-based network would be available for select airport personnel such as management and security officers.

The cell controller performs the function of determining which ESS network a mobile unit communicating with an RF port associated with the cell controller is operating on, and thereby controls the direction of communication from the cell controller to the network. The cell controller can verify the multiple levels of security provided in connection with the access by the mobile unit devices, and in addition can prioritize communications so that higher priority communications such as security communications are given greater access to the system during higher traffic conditions. For example, in the three-tier embodiment discussed above, the security network could have a feature to disallow all other network access in an emergency situation.

A similar multi-virtual LAN network may be also useful in a health care facility wherein different networks are used for security, medical care, personal and public information.

While there has been described what is believed to be claimed in the above-identified application those skilled in the art will recognize that other and further modifications may be made without departing from the scope of the invention and it is intended to claim all such changes and modifications as fall within the true scope of the invention.

I claim:

1. A method for operating multiple overlapping wireless local area subnetworks, the method comprising:

providing a common cell controller coupled to a plurality of RE ports, wherein the common cell controller in conjunction with each RF port provides wireless medium access to all of the wireless local area subnetworks for mobile units in a designated area associated with the RF port, wherein each RF port is configured to perform low level medium access control (MAC) functions and the cell controller is configured to perform high level MAC functions for the coupled plurality of RF ports;

using the cell controller to provide multiple service set identifications through each RF port, wherein each service set identification is associated with a corresponding wireless subnetwork,

wherein said RF ports are operated to perform low level MAC functions and to relay signals received from mobile units to said cell controller and to relay signals received from said cell controller to said mobile units,

and wherein said cell controller is operated to control association of said mobile units with said RF port, including sending and receiving association signals between said RF port and said cell controller, said association of said mobile units utilizing at least two wireless local area subnetworks occupying common physical space.

2. A method for operating a wireless local area network as specified in claim **1**, wherein signals are sent, between said RF port and said cell controller using a first data protocol, and wherein signals are sent between said RF ports and said mobile units using a second data protocol, and wherein said signals between said RF port and said cell controllers comprise data packets using said first data protocol encapsulating data packets using said second data protocol.

3. A method for operating a wireless local area network as specified in claim **2** wherein said first protocol is an Ethernet protocol.

4. A method for operating a wireless local area network as specified in claim **3** wherein said second protocol is an IEEE Standard 802.11 protocol.

5. A method for operating a wireless local area network as specified in claim **4** wherein said at least two wireless local area subnetworks comprise a subnetwork for public use and a subnetwork for secure use.

6. A method for operating a wireless local area network as specified in claim **5**, wherein upon activation of said subnetwork for secure use, suspending service on said subnetwork for public use.

7. The method of claim **1** wherein the RF port includes a radio module, a digital processor, random access memory and read-only memory, the method further comprising:

storing a bootloader program in said read-only memory,

operating said digital processor to download instructions from a computer to said random access memory using said bootloader program, and

operating said RF port under said downloaded instructions to send and receive messages over at least two wireless local area subnetworks occupying common physical space using said radio module.

8. A method as specified in claim **7**, wherein said step of operating said RF port comprises receiving messages from said computer including protocol message portions for RF message transmission, and transmitting said message including said protocol message portions as an RF signal.

9. A method as specified in claim **8**, wherein said step of operating said RF port comprises receiving RF messages having an RF protocol and sending said RF messages to said computer as data signals encapsulated in a further message protocol.

10. A method as specified in claim **9** further comprising interpreting said RF protocol using said downloaded instructions and sending said RF messages to said computer only if said RF messages include an identification of said RF port.

11. A method as specified in claim **7** wherein said downloaded instructions configure said computer and said RF port to operate as an access point for communication with mobile units.

12. A method as specified in claim **7** wherein said computer is operated to control association of said mobile units with said computer and RF port.

13. A method as specified in claim **7** wherein said downloaded instructions configure said computer and said RF port to operate as a mobile unit for communications with access points.

14. A method as specified in claim **7** wherein said downloaded instructions configure said computer and said RF port to operate as either an access point or a mobile unit under control instructions form said computer.

15. A method for transmitting signals having a wireless signal format using an RF port, the RF port having an Ethernet interface whereby the RF port is coupled to a wired network, and having a data processor and an RF module, wherein the RF port is configured to perform low level MAC functions, and wherein the wired network comprises at least one of a physical entity and a logical entity to perform high level MAC functions, the method comprising:

providing an Ethernet data packet formatted according to high level MAC functions over the wired network to said Ethernet interface, said Ethernet data packet encapsulating as data a data message having said wireless signal format according to high level MAC functions on said wired network;

operating said data processor to provide said data message to said RF module;

operating said RF module to transmit said data message as an RF signal to a mobile unit; and

operating said RF module to transmit said data message as an RF signal over at least two wireless local area subnetworks occupying common physical space.

16. A method as specified in claim **15** further comprising operating said data processor to perform a cyclic redundancy computation on said data message and adding the result thereof to said data message.

17. A method as specified in claim **15** further comprising operating said data processor to control said radio module.

18. A method for receiving signals having a wireless signal format including wireless address data and message data at an RF port, the RF port having a wired network interface whereby the RF port is coupled to a wired network, and having a data processor and an RF module, wherein the RF port is configured to perform low level MAC functions and the wired network is configured to perform high level MAC functions, the method comprising:

operating said RF module to receive RF signals from at least two wireless local area subnetworks occupying common physical space having said wireless signal format;

operating said data processor to receive wireless data signals from said RF module and provide data signals to said wired network interface comprising a data packet having a source address corresponding to said RF port formatted according to high level MAC functions on said wired network, said data packet including said wireless address data and said message data.

19. A method for receiving RF message signals having a wireless signal format including an address data format and message data using an RF port, the RF port having an Ethernet interface whereby the RF port is coupled to a wired network, and having a data processor and an RF module, wherein the RF port is configured to perform low level MAC functions and the wired network is configured to perform high level MAC functions, the method comprising:

receiving said RF message signals in said RF module from at least two wireless local area subnetworks occupying common physical space;

providing said signals as data signals to said data processor;

operating said data processor to interpret address data in said data signals; and,

in dependence on said address data, encapsulating said message data and address data in an Ethernet packet and providing said Ethernet packet to said Ethernet interface for transmission on said wired network according to high level MAC functions.

20. A method as specified in claim **19** wherein said data processor is operated to encapsulate said address data in said Ethernet packet.

21. A method as specified in claim **19** wherein said data processor is further operated to perform a cyclic redundancy computation on said message data and to compare the result thereof with corresponding data received in said data signals.

22. A method as specified in claim **19**, further comprising operating said data processor to control said radio module.

23. A simplified wireless local area network system comprising:

a computer having a data processor and a memory;

a plurality of RF ports, each RF port having an RF port data processor, an RF module and a data communications interface coupled to said computer,

a first program in said memory of said computer for operating said computer data processor to perform high level MAC functions for said plurality of RF parts, said functions including association with mobile units via at least two wireless local area subnetworks occupying common physical space; and

a second program for operating said RF port data processor to perform low level MAC functions.

24. A system as specified in claim **23** wherein said second program operates said RF port data processor to perform second wireless data communications functions, including control of said RF module.

25. A system as specified in claim **23** wherein said second program operates said RF port data processor to perform second wireless data communications functions, including cyclic redundancy check functions.

26. A system as specified in claim **23** wherein said second program is stored in said computer memory and wherein said RF port data processor is arranged to download said second program.

27. A wireless access device for providing wireless access to a communication system, comprising a modem for sending and receiving data messages between said communications system and an RF port, the RF port comprising a data interface coupled to said modem, a data processor and an RF module, said data processor being programmed to receive data messages from said modem, to format said messages for wireless data communications and to provide said formatted messages to said RF module for transmission by RF data signals to at least one mobile unit via at least two wireless local area subnetworks occupying common physical space, and to receive RF data signals from said at least one mobile unit via at least two wireless local area subnetworks occupying common physical space, and to provide data messages to said modem to be sent on said communi-

cations system, wherein said RF port performs low level MAC functions and said communication system performs high level MAC functions.

28. A wireless access device as specified in claim **27** wherein said communications system is a DSL communications system connected to the Internet, and wherein said modem comprises a DSL modem.

29. A wireless access device as specified in claim **27** wherein said communications system is a two-way cable communications system connected to the Internet, and wherein said modem comprises a cable modem.

30. A wireless access device as specified in claim **28** wherein said communication system comprises a fiber optic system, and wherein said modem comprises a fiber optical modem.

31. A method for providing wireless access to the Internet, comprising:

providing a modem coupled to the Internet and having a data communications interface connected to an RF port,

configuring said RF port for wireless data communication to a mobile unit having a predetermined wireless communications address, and

providing at least one mobile unit configured with said predetermined wireless communications address for conducting RF data communications with said RF port via at least two wireless local area subnetworks occupying common physical space, said RF port being arranged to relay communications between said mobile unit and said modem, wherein said RF port performs low level MAC functions and said Internet performs high level MAC functions.

32. The method specified in claim **31** wherein said step of providing said mobile unit, comprises providing a computer having an RF port.

33. A system for providing wireless data communications between mobile units and a wired network operating according to a wireless data communications protocol having high level MAC functions including association and roaming functions, comprising:

at least one RF port performing lower level MAC functions, said at least one RF port having an RF module for sending and receiving data messages to said at least one mobile unit using capable of operating via at least two wireless local area subnetworks occupying common physical space, having a wired interface for sending and receiving data messages to and from said wired network using a wired communications protocol, and a programmed processor for relaying data messages received on said wired interface using said RF communications protocol and for relaying data messages received by said RF module using said wired communications protocol; and

at least one cell controller for sending data messages to said wired interface of said RF port and for receiving data messages from said RF port wherein said cell controller performs said high level MAC functions.

34. A system as specified in claim **33**, wherein there are provided a plurality of said RF ports, and wherein said cell controller is arranged to address said data messages to said RF ports using said wired communication protocol.

35. A system as specified in claim **33** wherein said at least one mobile unit is associated with one of said RF ports, and wherein said processor is programmed to interpret source address data received in said RF communications protocol and for relaying a received message using said wired communications protocol only if said source address data corresponds.

36. A system as specified in claim **33** wherein said cell controller is arranged to provide messages to said RF port comprising mobile unit address data and message data encapsulated in data packet following said wired communication protocol.

37. A system as specified in claim **36** wherein said cell controller is arranged to provide said mobile unit address data and said message data in said RF communications protocol encapsulated in said wired communication format.

38. A system as specified in claim **33** wherein said RF port is arranged to encapsulate messages received by said RF module in a data packet using said wired communication protocol.

39. The method of claim **1** wherein the cell controller provides extended service set identifiers (ESS).

40. The method of claim **1** wherein the cell controller provides basic service set identifiers (BSS).

41. The method of claim **1** wherein the RF port allocates data bandwidth amongst the service set identifications based on commands from cell controller.

42. The method of claim **1** wherein the RF port generates an 802.11 beacon for each service set identifier.

43. The method of claim **1** wherein the cell controller determines which one of the multiple overlapping wireless local area subnetworks a mobile unit communicating through an RF port is operating on.

44. The method of claim **1** wherein the cell controller verifies levels of security provided in connection with access by mobile units to the multiple overlapping wireless local area subnetworks.

45. The method of claim **1** wherein the cell controller prioritizes communications through the multiple overlapping wireless local area subnetworks.

* * * * *

EXHIBIT B

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(54) **SECURITY IN MULTIPLE WIRELESS LOCAL AREA NETWORKS**

(75) Inventor: **Robert Beach**, Los Altos, CA (US)

(73) Assignee: **Symbol Technologies, Inc.**, Holtsville, NY (US)

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(58) **Field of Classification Search** 370/401, 370/338, 466, 419–420
See application file for complete search history.

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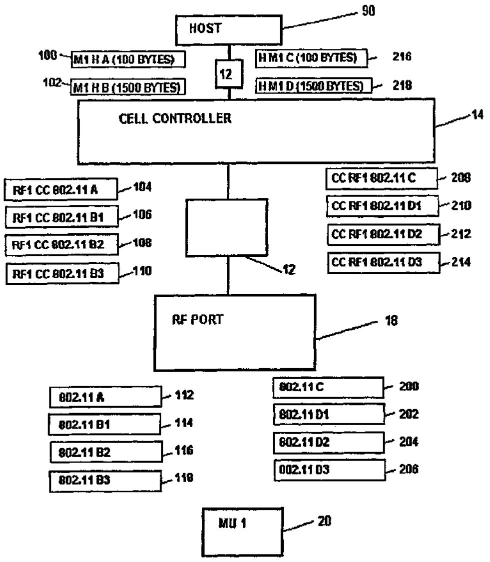
Primary Examiner—Chirag G. Shah
(74) *Attorney, Agent, or Firm*—Ingrassia Fisher & Lorenz, P.C.

(57) **ABSTRACT**

A wireless local area network is provided with simplified RF ports which are configured to provide lower level media access control functions. Higher level media access control functions are provided in a cell controller, which may service one or more RF ports that are capable of operating based on a pre-assigned security level. Mobile units can also be configured with the higher level media access control functions being performed in a host processor.

16 Claims, 7 Drawing Sheets



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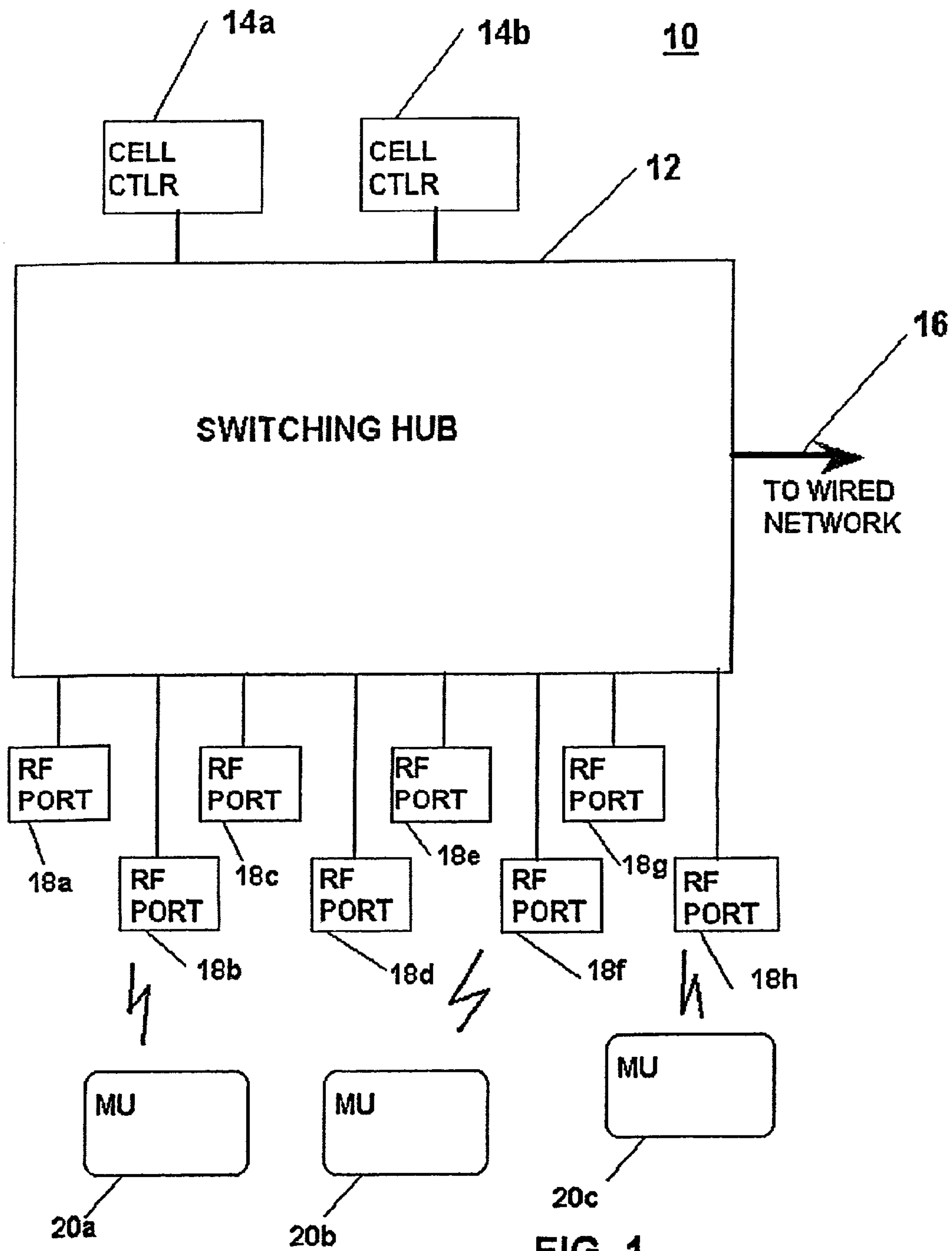


14a
14b
10
CELL CTLR
CELL CTLR
12
16
SWITCHING HUB
TO WIRED NETWORK
RF PORT
RF PORT
RF PORT
RF PORT
RF PORT
RF PORT
RF PORT
RF PORT
18a
18b
18c
18d
18e
18f
18g
18h
MU
MU
MU
20a
20b
20c

FIG. 1

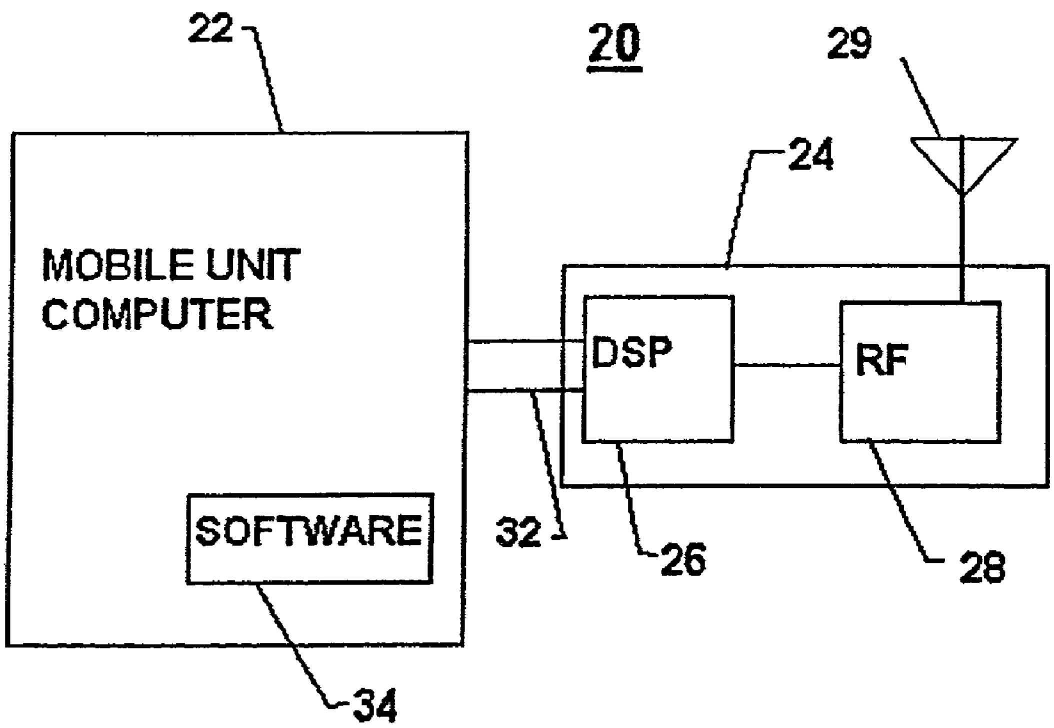


FIG. 2

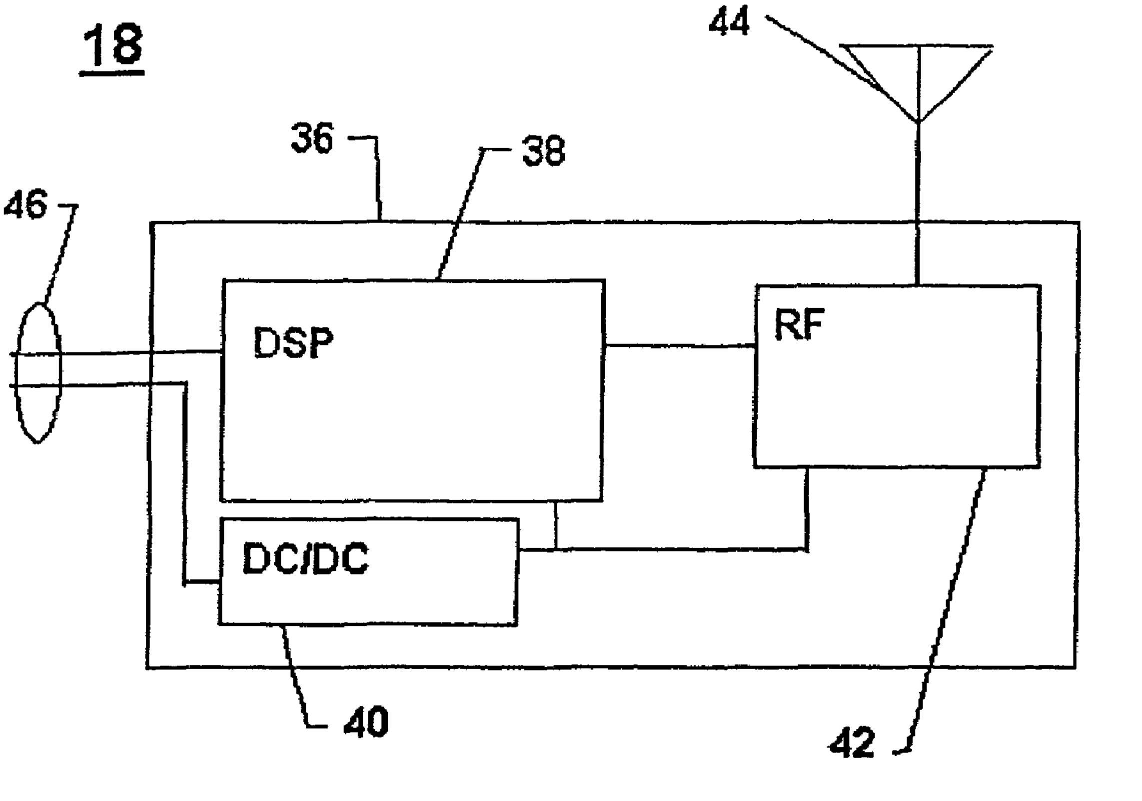


FIG.3

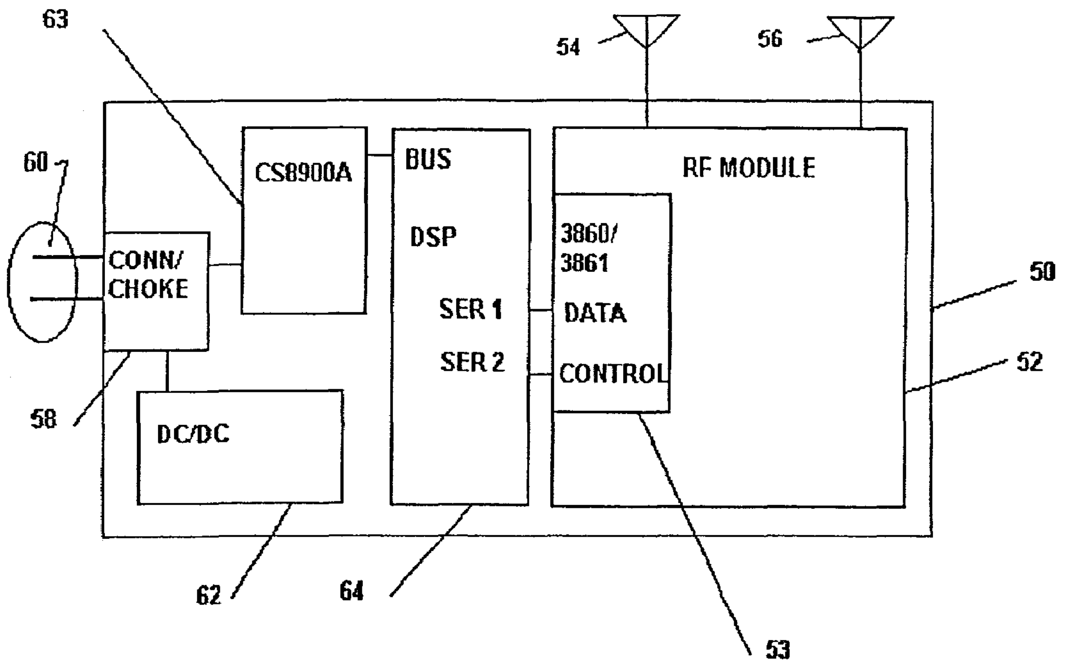

63
54
56
60
CS8900A
BUS
RF MODULE
DSP
3860/
3861
CONN/
CHOKE
SER 1
DATA
50
SER 2
CONTROL
52
58
DC/DC
62
64
53

FIG. 4

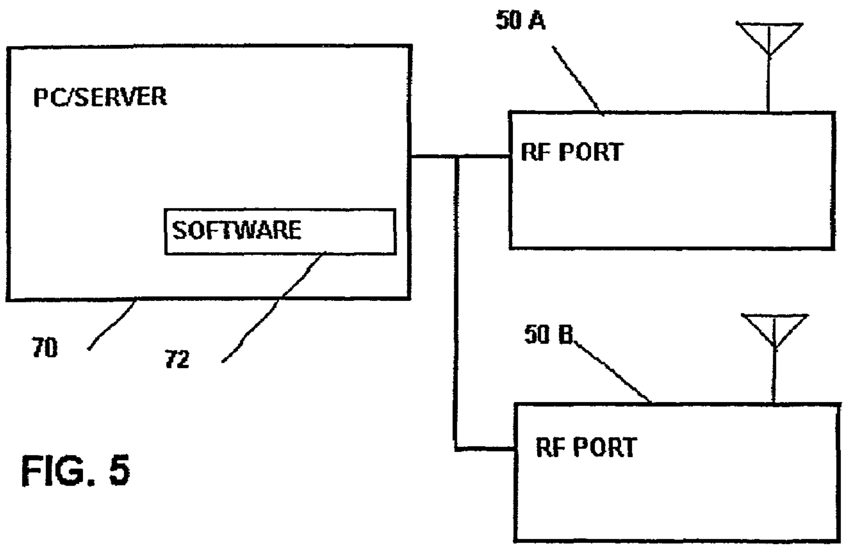

50 A
PC/SERVER
RF PORT
SOFTWARE
70
72
50 B
RF PORT

FIG. 5

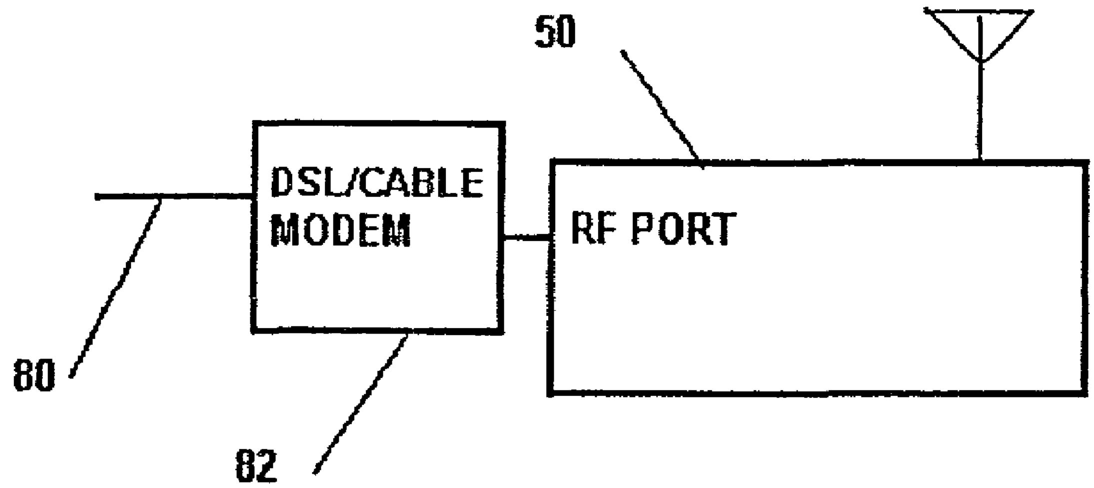


FIG.6

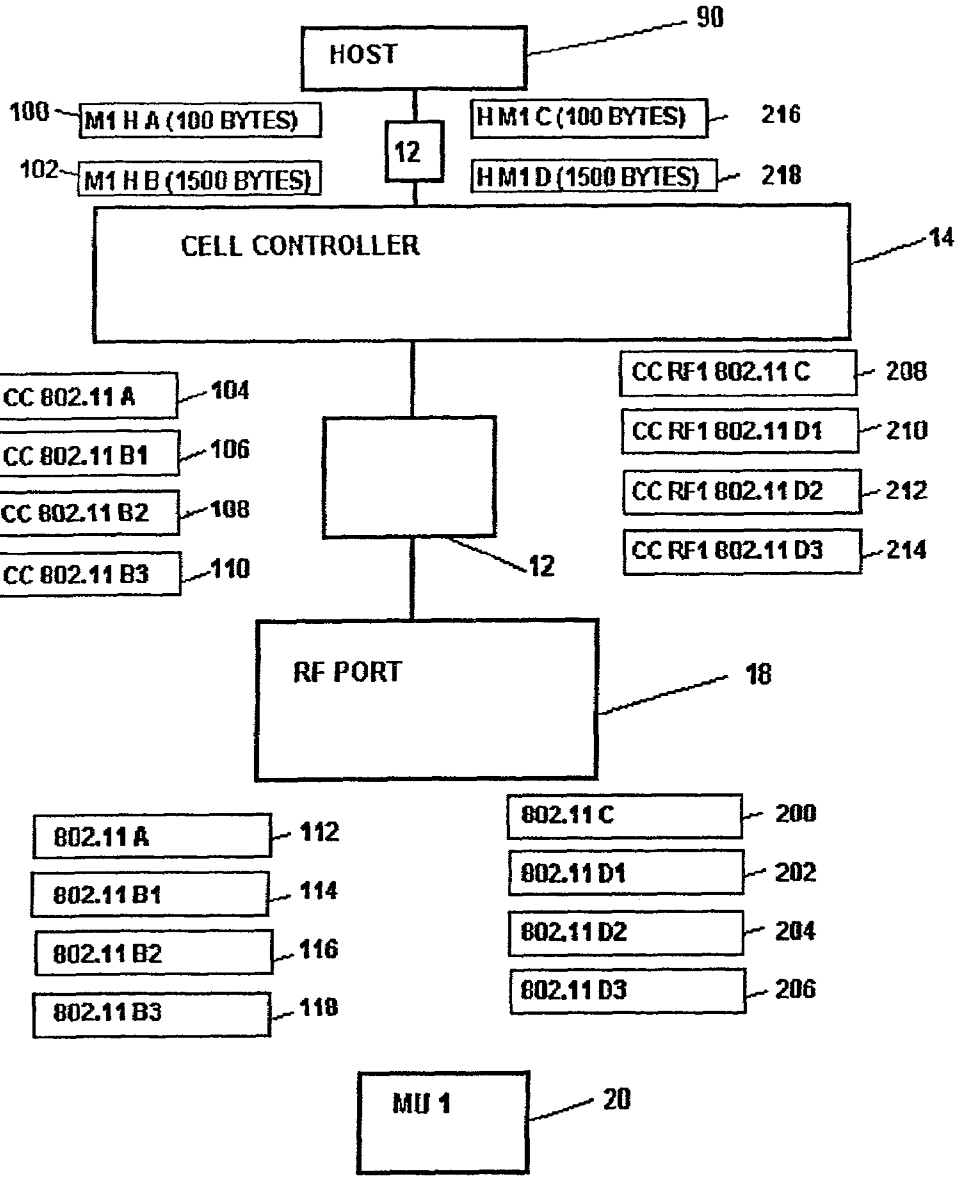
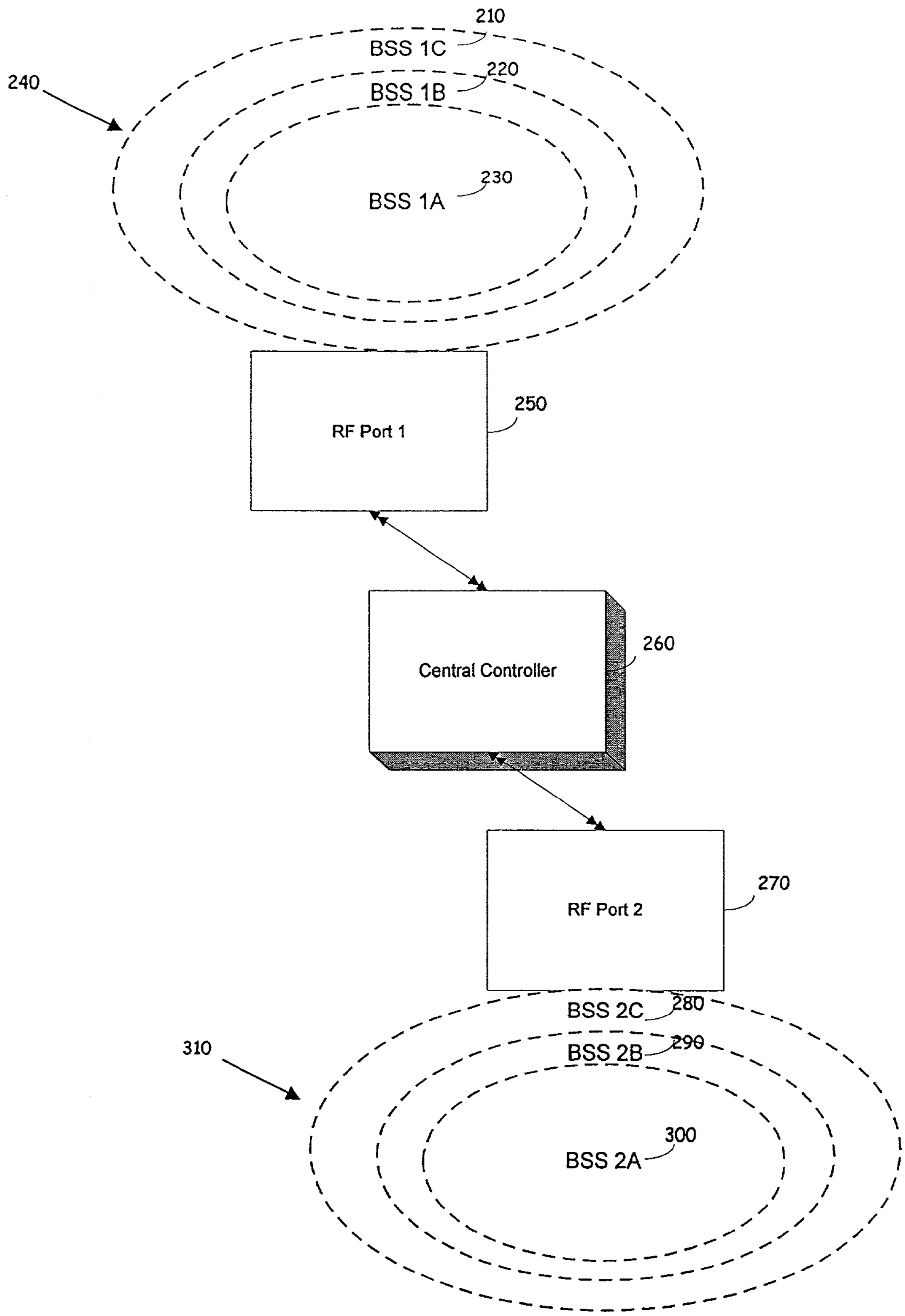

HOST
90
100
M1 H A (100 BYTES)
102
M1 H B (1500 BYTES)
12
H M1 C (100 BYTES)
216
H M1 D (1500 BYTES)
218
CELL CONTROLLER
14
RF1 CC 802.11 A
104
RF1 CC 802.11 B1
106
RF1 CC 802.11 B2
108
RF1 CC 802.11 B3
110
CC RF1 802.11 C
208
CC RF1 802.11 D1
210
CC RF1 802.11 D2
212
CC RF1 802.11 D3
214
12
RF PORT
18
802.11 A
112
802.11 B1
114
802.11 B2
116
802.11 B3
118
802.11 C
200
802.11 D1
202
802.11 D2
204
802.11 D3
206
MU 1
20

FIG. 7

FIG. 8


210
BSS 1C
220
BSS 1B
240
230
BSS 1A
RF Port 1
250
Central Controller
260
RF Port 2
270
BSS 2C
280
BSS 2B
290
310
300
BSS 2A

SECURITY IN MULTIPLE WIRELESS LOCAL AREA NETWORKS

REFERENCE TO PRIOR APPLICATION

This application is a continuation-in-part of pending application Ser. No. 09/780,741, filed Feb. 9, 2001, which is a continuation-in-part of pending application Ser. No. 09/528,697, filed Mar. 17, 2000.

BACKGROUND OF INVENTION

This invention relates to wireless data communications networks, and in particular to arrangements for communications between mobile data handling units and a central computer using wireless data communications.

The assignee of the present invention supplies a wireless data communications system known as the Spectrum 24 System, which follows the radio data communications protocol of IEEE Standard 802.11. In the system as implemented, mobile units are in data communication with a central computer through access points. The access points may communicate with a central computer or computers over a wired network. Each of the mobile units associates itself with one of the access points. The access points in this system are functional to perform all the implemented requirements of the standard protocol, including, association and roaming functions, packet formulation and parsing, packet fragmentation and re-assembly encryption and system access control. In order to maintain order and reduce radio communications each access point must determine which of the data communications received over the wired network from the central computer is destined for a mobile unit associated with that particular access point. This requirement adds significant computational capacity to the access point, increasing the cost thereof.

In addition, in applications that must support a high volume of data communications from multiple users, such as systems supporting a self-service shopping system, hospital systems, systems that include paging or voice data links to many users, or systems supporting communicating with electronic shelf labels, additional access points are required to support the data communications traffic, increasing the overall system cost.

The cost of an operational access point is dependent not only on the complexity thereof and the requirement for high speed processing of data pockets for purposes of selecting those destined for mobile units associated with an access point, but the additional cost of the installation of electrical power to the location of the access point, and the cost of a power supply to convert AC electrical power to DC power for the circuits of the access point. Further cost may be involved in physically mounting the access point hardware and antenna.

In prior systems each access point is connected on an Ethernet wired network to the central computer. The access points are required to determine the identity of mobile units which have become associated with them and to extract from the data packets on the Ethernet network those packets addressed to a mobile unit associated with the access point. This requirement has led to significant processing burden for the access points and led to increased cost for the access points.

In the system described in my prior published International Patent Application WO 099 37047, published Jul. 22, 1999, the central computer communicates over an Ethernet wired network with an intelligent switching hub. Alternately a token ring network can be used. The switching hub determines the destination of each packet and routes packets to an access point if the destination of the packet is a mobile unit associated with the access point. To achieve this function, the hub is an intelligent hub which maintains a routing list of mobile units and their associated access point according to the port of the hub.

In practice, the hub need only maintain a source list for those access points connected to the hub and mobile units associated with the access points connected to the hub. Thus, if a packet is received at a hub over the Ethernet with a destination address which is not associated with that hub, the packet is ignored. The hub will route the packet to an access point only if the destination address of the packet is identified on the list. When a packet is received on a hub port associated with a communications line connected to an access point, the source address is associated with the hub port in the list. The packet is routed either to the Ethernet connection or to another port according to the destination address.

By determining destination address in the hub and maintaining the association of a mobile unit address with an access point connected to a port of the hub in a routing list of the hub, the functionality required of the access points is greatly reduced. The access point acts merely as a conduit sending RF transmissions of packets received on its communication line, and receiving transmissions from associated mobile units and providing Ethernet packets to the hub. In addition, the access point must provide mobile unit association functions and other 802.11 protocol functions, as provided in the Spectrum 24 system, and may also provide proxy polling responses for associated mobile units that are in power saving mode.

The prior system may have a large number of access points, each with a memory containing program instructions for carrying out the various required functions. This distribution of processing makes it difficult to upgrade a system or to provide changes in system configuration because any upgrade or change may require changes to the program code in each of the access points. Such distribution of processing functions also makes system management functions, such as load balancing or access control more difficult.

It is therefore an object of the present invention to provide an improved wireless data communications methods and systems having lower cost, to enable the economical provision of reliable wireless data communications with increased capacity in complex installations or at reasonable cost or simple installations.

SUMMARY OF THE INVENTION

In accordance with the invention there is provided a system for providing wireless data communications between mobile units and a wired network. The system includes a plurality of RF ports having at least one data interface and arranged to receive formatted data signals at the data interface and transmit corresponding RF data signals and arranged to receive RF data signals and provide corresponding formatted data signal. There is also provided at least one cell controller, arranged to receive data signals from the wired network and to provide formatted data signals corresponding thereto and to receive formatted data signals and to provide data signals corresponding thereto to the wired network, the cell controller controls association of mobile units with one of the RF ports, provides formatted data

signals for said mobile units to an associated RF port and receives formatted data signals from the mobile unit from the associated RF port.

In accordance with the invention there is provided an improvement in a wireless data communications network coupled to a data processing system, having a plurality of RF ports and mobile units, wherein the mobile units associate with one of the RF data communications ports to conduct data communications with said data processing system. The mobile units are assigned to one of the RF ports by a cell controller, and the cell controller is arranged to receive first data communications from the data processing system and to relay the data communications to an assigned RF port and to receive second data communications from the RF ports and relay the second data communications to the data processing system.

In accordance with the invention there is provided a method for operating a wireless local area network having at least one RF port, a plurality of mobile units and a cell controller coupled to the RF port. The RF is operated port to relay signals received from mobile units to the cell controller and to relay signals received from the cell controller to the mobile units. The cell controller is operated to control association of the mobile units with the RF port, including sending and receiving association signals between the RF port and the cell controller, and to send messages to and from the mobile unit via the RF ports.

In accordance with the invention there is provided an improvement in a mobile unit for use in a wireless data communications system, wherein the unit has a data processor and programs for the data processor and a wireless network adapter having a programmed processor and a radio module. The programmed processor performs first communications processor functions including control of the radio module and the data processor operates under the programs to perform second communications processor functions, including association with a radio access location of the wireless data communications system.

According to the invention there is provided an improvement in a wireless data communications system for providing data communications following a standardized protocol, wherein the protocol includes association of mobile units with radio access locations. At least one RF port is provided at a radio access location, which RF port comprises a radio module and an RF port processor in data communications with a programmed computer. The RF port processor performs first functions of the standardized protocol and the programmed computer performs second functions of the standardized protocol, including the association of mobile units with said radio access location.

According to the invention there is provided an RF port for use in a wireless data communications system comprising a radio module having a data interface and a transmitter/receiver for wireless data communications; and a digital signal processor having first and second data communications ports, random access memory and read-only memory. The second data communications port is coupled to the data interface of said radio module. The read-only memory is provided with a bootloader program for controlling the digital signal processor to load program instructions to the random access memory via the first communications port. According to the invention there is provided a method for operating an RF port having a radio module, a digital processor, random access memory and read-only memory. A bootloader program is stored in the read-only memory. The digital processor is operated to download instructions from a computer to the random access memory using the bootloader program and the RF port is operated under the downloaded instructions to send and receive messages using the radio module.

According to the invention there is provided a method for transmitting signals having a wireless signal format using an RF port having a wired network interface, a data processor and an RF module. Signals are provided to the wired network interface having wireless address data and message data within a data packet addressed to the RF port using a protocol for the wired network. The processor is operated to provide wireless data signals having the wireless signal format for the address data and the message data to said RF module and operating the RF module is operated to transmit the wireless data signals as an RF signal modulated with the wireless signal format.

According to the invention there is provided a method for transmitting signals having a wireless signal format using an RF port having an Ethernet interface, a data processor and an RF module. An Ethernet data packet is provided to the Ethernet interface, the Ethernet data packet encapsulating as data a data message having the wireless signal format. The data processor is operated to provide the data message to the RF module. The RF module is operated to transmit the data message as an RF signal.

According to the invention there is provided a method for receiving signals having a wireless signal format including wireless address data and message data at an RF port having a wired network interface, a data processor and an RF module. The RF module is operated to receive RF signals having the wireless signal format. The data processor is operated to receive wireless data signals from the RF module and provide data signals to the wired network interface comprising a data packet having a source address corresponding to the RF port using a protocol for the wired network, the data packet including the wireless address data and the message data.

According to the invention there is provided a method for receiving RF message signals having a wireless signal format including an address data format and message data using an RF port having an Ethernet interface, a data processor and an RF module. The RF message signals are received in the RF module and provided as data signals to the data processor. The data processor is operated to interpret address data in the data signals and, in dependence on the address data, said message data and said address data is encapsulated in an Ethernet packet, which is provided to the Ethernet interface.

In accordance with the invention there is provided a simplified wireless local area network system including a computer having a data processor and a memory, an RF port having an RF port data processor, an RF module and a data communications interface coupled to the computer. A first program is provided in the memory of the computer for operating the computer data processor to perform first wireless data communications functions, including association with mobile units. A second program is provided for operating the RF port data processor to perform second wireless data communications functions.

According to the invention there is provided a wireless access device for providing wireless access to a communication system. The device includes a modem for sending and receiving data messages on the communications system and an RF port, having a data interface coupled to the modem, a data processor and an RF module. The data is programmed to receive data messages from the modem, to format the messages for wireless data communications and to provide the formatted messages to the RF module for transmission

by RF data signals to at least one remote station, and to receive RF data signals from the at least one remote station, and to provide data messages to the modem to be sent on the communications system.

According to the invention there is provided a method for providing wireless access to the Internet. A modem having a data communications interface connected to an RF port is connected to the Internet. The RF port is configured for wireless data communication to at least one mobile unit having a predetermined wireless communications address. A mobile unit configured with the predetermined wireless communications address is provided for conducting RF data communications with the RF port. The RF port is arranged to relay communications between the mobile unit and the modem.

The apparatus and methods of the present invention provide RF ports as radio access locations which are less expensive than known access points and provide greater system management and flexibility. Much of the software used for controlling communications to and from mobile units is performed in a controller wherein software upgrades and changes are easily implemented. According to some embodiments, wherein instructions are downloaded to RF ports, it becomes easy to upgrade RF port instructions. System control is centralized, making management easier and enabling changes to access control and encryption functions. Priority for traffic purposes can also be established to facilitate digital telephony by giving priority to voice traffic. Accordingly, a system is provided that has significant flexibility using common RF port hardware to provide a wireless LAN having from one to hundreds of radio access locations.

According to the invention, the same RF port may provide multiple ESS identifications such that each ESS identification is associated with a separate virtual wireless local area network having its own policies and security.

For a better understanding of the present invention, together with other and further embodiments thereof, reference is made to the following description, taken in conjunction with the accompanying drawings, and its scope will be pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a wireless communications system in accordance with the present invention.

FIG. **2** is a block diagram illustrating one example of a mobile unit arranged to be used in the system of FIG. **1**.

FIG. **3** is a block diagram illustrating one example of an RF port for the system of FIG. **1**.

FIG. **4** is a more detailed block diagram of a preferred embodiment of an RF port in accordance with the invention.

FIG. **5** is a block diagram of an arrangement of a computer and RF port for providing a simplified wireless local area network according to the present invention.

FIG. **6** is a block diagram of an arrangement for providing wireless access to the Internet using the RF port of the present invention.

FIG. **7** is a diagram showing signal format according to one embodiment of the invention.

FIG. **8** is a diagram showing an compilation of RF ports having multiple ESS arrangements for providing overlapping, multiple wireless networks.

DESCRIPTION OF THE INVENTION

Referring to FIG. **1**, there is shown an example of a wireless data communications system **10** according to the present invention for providing data communications between a central computer or a collection of computers on a wired network **16** and a plurality of mobile units **20**. While prior systems used access points at each radio access location, where the access points are capable of managing wireless communications with mobile units, the system of FIG. **1** uses simplified RF ports **18** at each radio access location to provide radio packet communications with the mobile units **20** using a wireless communications protocol, such as EEEE Standard 802.11, whereby the radio modules in the mobile units **20** monitor polling signals from the RF ports **18**, which are originated by the cell controllers **14** and associate with an RF port **18** for purposes of data communications. The system arrangement of FIG. **1** is especially effective in a large wireless local area network (LAN) system wherein it may be necessary to provide a large number of radio access locations. Typically such systems, operating at low power microwave frequencies, require radio access locations at about every 100 feet. Where the wireless LAN system must operate with mobile units, for example, portable computers or similar devices, located throughout a large facility, such as a business, hospital complex or university campus, many such radio access locations may be required, possibly several hundred. Accordingly there is an incentive to reduce the cost of the installation at each radio access location. According to the present invention the system configuration and operation are redesigned to reduce the cost of each individual radio access point. In addition, the system of the present invention provides a concentration of operational control in one or more central controllers **14**, making management of the system easier and making modifications and upgrades easier to install.

According to the invention, much of the functionality of the 802.11 protocol associated with the conventional access point, is removed from the device located at the radio access location and provided in a cell controller **14**, which may be located in conjunction with a switching hub **12**, connected to the wired network **16**, with which the wireless network **10** is associated. In particular the usual "access point" device is replaced with a simpler device **18**, herein referred to as an "RF port" which contains the RF module, which may be the same RF module used in the prior art access point, and simplified digital circuits to perform only a limited portion of the 802.11 media access control (MAC) functions performed by the prior art access point. In particular the RF port **18** preferably performs only functions of the access point that require a lower level of processing resources in terms of processor capacity and software complexity (memory requirement), and which are time critical. Other functions that are more processor intensive and require more complex programming, and which are not time critical, are relegated to one or more "cell controllers" **14**, which may perform these more complex functions for a plurality of RF ports **18**.

In order to perform the higher level processing functions of the access point in the cell controller **14**, according to the present invention, all messages directed to or from mobile units **20** associated with a particular RF port **18** are processed in a cell controller **14**. A system may have one or more cell controllers, which may comprise, e.g. Pentium-type board level computers, each of which is arranged and programmed to handle data message traffic and mobile unit associations for a selected plurality of RF ports **18**. A

switching hub **12** may be interposed to provide message switching among the wired network connected to communications line **16**, RF ports **18** and cell controllers **14**. Each of the one or more cell controllers **14** acts as a virtual "access point" for traffic addressed to its associated RF ports **18** and to the mobile units **20** associated with those RF ports. When a message is addressed to a mobile unit **20** is received on line **16**, switching hub **12** directs the message to the appropriate cell controller **14**, which reformats the message and relays the message to the appropriate RF port **18**, again through switching hub **12**. When the message is received by an RF port **18**, it is converted to a radio message and sent to the mobile unit **20** with a minimum of processing.

Likewise, when a message is received from a mobile unit **20** by an RF port **18**, it is converted to a digital message packet and relayed to the cell controller **14** associated with the RF port **18** through the switching hub **12**. The cell controller **14** parses the message for further relay in the system.

An important feature of a preferred embodiment of the invention is the fact that mobile unit association with the RF ports **18** is a function handled by the cell controller **14**. Accordingly, when a mobile unit **20** first becomes active, it sends an association request signal in response to a beacon signal sent by an RF port **18** (in response to direction by the cell controller). The association request signal is relayed by the RF port **18** to the cell controller **14**, which performs the processing required for association, including consideration of RF port loading. Cell controller **14** generates appropriate response signals to be sent by the RF port **18** to the mobile unit **20**. The cell controller **14** is in an appropriate position to evaluate the loading of the RF ports **18** under its control, and may therefore easily perform load leveling functions, for example, by providing a message to RF port **18** accepting or declining an association request. In addition, the cell controller **14** may receive load messages from other cell controllers **14** in the system **10** and thereby coordinate overall load management. As a mobile unit **20** moves from a location serviced by one RF port **18** to a location serviced by a different RF port **18**, the cell controller **14** receives information from the mobile unit **20** indicative of its reception of beacon signals from the various RF ports in the system and performs the necessary functions to support roaming of mobile unit **20**.

While in the system **10** of FIG. **1** the cell controllers **14** are shown as separate computers connected to switching hub **12**, the term "cell controller" is intended to refer to the logical functions performed by these computers rather than the computers themselves. As will become apparent, the cell controller may be implemented in a variety of ways other than as shown in the exemplary system **10** of FIG. **1**.

Implementation of a simplified RF port is achieved by performing "higher level" functions of the 802.11 protocol Media Access Control (MAC) in the cell controller and performing "lower level" functions in a simplified RF port.

The lower level functions are those that are hardware intensive and often time critical. The higher level functions are those that are software intensive and not time critical. One possible division of the exemplary 802.11 MAC functions is as follows:

- Lower Level Functions (preferably to be performed at RF port)
  - Cyclic Redundancy Check (CRC)
  - Network Activity Vector (NAV)
  - Ready to Send/Clear to Send (RTS/CTS)
  - Header generation/parsing
  - Collision Avoidance
  - Frequency Hopping
  - Ack parsing/generating
  - Retransmission timeout
- Higher Level Functions (preferably to be performed at Cell Controller)
  - Association processing
  - Roaming
  - Retransmission
  - Rate Control
  - Host Interface

The following optional (higher or lower) level MAC functions can be placed in either the higher or lower level categories.

- Wired Equivalent Privacy encryption/decryption (WEP)
- Fragmentation/Reassembly
- Data Movement
- Power Save Polling Support (PSP)

According to a preferred arrangement of the system of the invention, the lower level MAC functions are provided at the RF port, the higher level MAC functions are provided in the cell controller and the optional level functions can be provided at either the cell controller or the RF port.

A major advantage of the invention is a cost savings in hardware, processor capacity and storage capacity for the RF port. Since a system with, for example, one hundred or more radio access locations may be implemented with one or two cell controllers, the processor hardware and memory required for the higher level MAC functions need be provided only at the cell controllers. In fact, the capabilities of the overall system, for WEP encryption and other special functions, can be increased at modest cost by using a high performance board level personal computer or even a host computer as a cell controller.

By eliminating the higher level MAC functions from the radio access locations, the cost of the devices installed at those locations can be significantly reduced because of lower processor capacity and storage.

In connection with association and roaming functions the RF ports **18** provide beacon signals in response to commands generated by the cell controller **14**. When an association sequence is initiated by a mobile unit, the RF port **18** relays the association messages between the mobile unit **20** and the cell controller **14** during the association process, which is handled by the cell controller **14**.

In connection with message traffic to a mobile unit **20** from a network processor, message packets are routed by switching hub **12** to the cell controller **14** responsible for the mobile unit **20** addressed. The message is buffered and formatted by the cell controller **14** and in a preferred arrangement encapsulated by the cell controller **14** as a mobile unit packet within a wired network packet addressed to the responsible RF port **18**. This packet is routed to the RF port **18**. The RF port **18** extracts the mobile unit packet from the message and sends the packet to mobile unit **20** as a radio signal. The RF port **14** may also provide a CRC calculation and generate CRC data to be added to the message. The mobile unit **20** responds with an acknowledgment signal to the RF port **18**, which generates and sends an acknowledgment status message to cell controller **14**.

In connection with messages for systems connected to the wired network **16**, the mobile unit **20** sends a packet to the RF port **18** by radio signal. The RF port **18** filters received radio message packets according to the BSS (Basic Service Set) identifier in the packet and, if the packet has a BSS identifier associated with the RF port **18**, performs the CRC

check as the packet is received. The RF port **14** then generates and sends an acknowledgment signal to the mobile unit **20** and sends the received packet to cell controller **14**. Cell controller **14** buffers, parses and, if necessary, decrypts the packet and routes the packet to the host on network **16** through hub **12**.

The arrangement of RF port **18** maybe identical to current access points used in the Spectrum 24 system with some of the access point software non-functional. Preferably the RF ports are simplified to reduce cost and power consumption. To reduce installation expenses the RF ports are powered via an Ethernet cable, which also connects RF ports **18** to switching hub **12** or to cell controller **14**. The RF ports can be arranged in a small package (e.g. portable radio size) with integrated diversity antennas and arranged for easy mounting, such as by adhesive tape or Velcro. Connection to the switching hub **12** is by Ethernet cable which is also provided with D.C. power, such as by use of a choke circuit, such as Pulse Model PO421 as described in my referenced International Application. The choke circuit may be built into an Ethernet connector and is available in this configuration.

The RF port **18** does not have to perform Ethernet address filtering and does not have to perform 802.11 association and roaming functions and can therefore have a lower level of processor capacity, software support, memory and power consumption. In one embodiment shown in FIG. **3** the RF port **18** includes only a digital signal processor (DSP) **38** which includes internal RAM and ROM. The DSP **38**, which may be one of the Texas Instruments TMS 320 family of DSP processor, such as the 5000 series, specifically the TMS 320 UC 5402 or the TMS 320 VC 5402. This DSP provides an interface between the Ethernet cable **46** and the RF module **42** in RF port **18**, as shown in FIG. **3**. The RF module **42** is provided in housing **36** with DSP **38**, DC/DC power supply **40** and carrying one or more antennas **44**. RF module **42** includes a 3860 or 3861 baseband processor, such as HFA 3860B, to interface with the digital portion of the RF port **18**, specifically DPS **38**. In one arrangement the ROM memory of the DSP **38** can be provided with "bootloader" firmware that downloads the necessary DSP software instructions from the cell controller **14** upon startup of the RF port **18**, and loads the instruction into the RAM of the DSP **38**.

The processors that are currently preferred as a possible lower level MAC engine are the TMS320UC5402 and the TMS320VC5402. These parts are functionally identical except for differences in power consumption (the VC5402 is currently in production and while the UC5402 is still being sampled). The basic configuration of the UC5402/VC5402 is:

- 100 MIPS execution rate
- 8 KB on chip ROM (organized as 4K×16 bits)
- 32KB on chip RAM (organized as 16K×16 bits)
- Two 16 bit timers with 1 μs or better resolution
- Two High speed, full duplex serial ports (up to 50 Mbits/sec each) with smart DMA channel support
- One High speed 8 bit wide host/parallel port (160 Mbit/sec)
- Six DMA channels for general purpose use
- 16 bit external memory/IO Bus with internal wait state generation
- 16 interrupts with 3 instruction (30 ns) worst case latency
- 0.54 mW/MHz power consumption (30 mA@1.8 v at 100 MHz)
- Low Power Modes (6 mA, 2 mA, 2 μA depending on setting)
- Internal PLL that generates the system clock with an external crystal

This section will describe the use of a 5402 DSP **38** as a MAC engine for 11 Mbit/sec 802.11 DS systems. It could clearly be used in FH systems as well. We will focus on the how the 5402 interfaces to the Intersil 3860/1 baseband processor in RF module **42** and how it implements the lower level MAC functions.

The first issue is how the 5402 DSP **38** interfaces to the 3861 (much of what is said applies to the 3860 as well) and the rest of the RF module **42**. As shown in FIG. **4**, the 3861 processor **53** in RF module **52** of RF port **50** has 2 major interfaces, both serial. The first interface, labeled DATA, is used to transfer data between the MAC engine comprising DSP **64** and the 3861. It has four lines: TxD, TxC, RxD, and RxC and operates at up to 11 Mbits/sec. The exact rate depends on the transfer rate of the packet. The clock signals of both interfaces are generated by the 3861 and so transfers are controlled by the 3861. Both can be halted at any time by the 3861 as well as change rate. The second serial interface, labeled CONTROL is used to load commands into the 3861 and read status information from the 3861. This interface is a 4 wire bi-directional interface using one data line, one clock line, one "direction control" line, and a chip select line. This serial interface also can operate at up to 11 Mbits/sec. In addition to the serial interfaces, there are additional control and status lines such as Reset, TX_PE, RX_PE, TX_RDY, etc.

The 5402 DSP **38** has two sets of full duplex serial interfaces that are capable of operation up to 50 Mbits/sec (given a 100 MHz clock). They can be clocked using internal or external sources. In this design one of the sets of serial interfaces, labeled SER1, is used to connect to the high speed data lines of the 3861 interface **53**. The 5402 DSP **38** interfaces have the same basic lines (RxD, RxC, TxD, TxC) as does the 3861 and so they connect with minimal trouble. Although the 5402 uses 1.8 v for its core, its I/O lines are 3.3 v tolerant and so can interface to the 3861 without converters. In addition, they are fully static and so can deal the start/stop operation of the clock lines from the 3861.

Data transfer will be done under DMA control within the 5402 using what TI calls "Auto Buffering Mode." This provides essentially dedicated DMA channels for each serial port interface (two DMA channels per serial port interface). These channels access an independently operating bank of SRAM and so transfers have no impact on CPU performance. The CPU can start transfers in either direction and be notified via interrupt on their completion.

Interfacing to the control serial port on the 3861 interface **53** can be done in three different ways. The first, illustrated in FIG. **4**, utilizes the second serial port, labeled SER 2 on the 5402 DSP **64** with a small amount of combinatorial logic/buffering to convert between the single data line of the 3861 and the dual data lines of the 5402. Another approach is to use an external shift register that would perform serial/parallel conversion. This register would sit on the I/O bus of the 5402 and would be loaded/read by the 5402 and data shifted between it and the 3861. The third approach is to use an external buffer/latch on the 5402 I/O bus and "bit bang" the clock/data lines to the 3861. The second or third approaches free up the second serial channel for more other use such as providing high speed serial interfaces such as Ethernet or USB and in some applications would be preferred over the first. All require a small amount of external combinatorial logic and so the cost of all solutions is about the same.

The same logic would apply to interfacing to the synthesizer. It is accessed even less often than the control port of the 3861 and so a "bit banging" approach would work fine.

Finally, interfacing to the various control and status lines presented by the 3861 can be done via simple bidirectional register/latch connected to the I/O bus of the 5402. The 5402 can read/write this register as it needs to control and monitor the 3861. It would be possible to combine all control/monitor functions (including the serial control interface) into a single 16 bit buffered register latch. Parallel control/status lines would be connected to particular lines of this latch. Serial control interfaces would also be connected and "bit banged" as necessary to move data between the 5402 and 3861.

The arrangement shown in FIG. **4** uses a Crystal CS 8900 A Ethernet controller **63** coupled to the parallel port of DSP **64** to interface to the Ethernet port **58**. An Ethernet connector/choke **58** receives cable **60** and provides DC power from cable **60** to DC/DC power supply **62**. The FIG. **4** RF port **50** includes spaced diversity antennas **54**, **56** to improve reception in multipath conditions.

A premise of this design is that the TI DSP is capable of implementing all lower level MAC functions without external hardware assistance. This, of course, is the most demanding model but we will find that the 5402 is up to the task. The most computational demanding tasks are the CRC-32 and WEP processing. The CRC-32 calculation is performed over the entire packet and must be completed in time to generate an ACK should the CRC turn out to be correct (or to attach the calculation result to an outgoing packet on transmission). This means that the CRC calculation must be performed in near real-time during packet transfer between the 3861 and 5402. TI has shown in an application note that a CRC-32 calculation can be made by a 5000 series DSP in 13 instructions. At 100 MIPS this is about 130 ns. At 11 Mbit/sec, a byte takes about 770 ns to transfer and so we have plenty of time to do the CRC. When receiving a packet, the serial port would be transferring the data from the 3861 to SRAM within the 5402. At the same time the CPU within the 5402 would be reading each received byte from SRAM and calculating the CRC. It would of course have to make sure that it did not overrun the receive buffer, but that would be a relatively simple task. Much the same process would happen during transmission. In either case, the CPU has lots of time to do the CRC.

The WEP processing if performed in the RF port **50**, is a harder function to perform than CRC-32 since it includes both an RC4 encryption function and a second CRC-32. At the same time it does not need to be completed prior to ACK generation/reception nor is performed on every packet (just data packets). The RC4 encryption function consists of two parts: building the encryption table (a 256 byte table) using the selected key and doing the encryption/decryption process. Based on sample code, it is estimated that building the table would require about 1200 instructions (12 ms at 100 MIPS) and the encryption/decryption process would require about 12 instructions/byte. There is no difference in this cost for 40 or 128 bit keys. The WEP CRC-32 would require another 13 instructions per byte.

The per byte computational burden for WEP would thus be about 25 instructions or about 250 ns at 100 MIPS. When added to the packet CRC-32, the total load would be around 38 instructions/byte. As we pointed out, at 11 Mbit/sec we have about 77 instructions/byte available, so we are spending about 50% of the CPU on CRC/WEP tasks. The biggest issue is the 1200 clocks (12 us) required to build the encryption table during receive (For transmission, the calculation can be done prior to starting packet transfer). Pausing to create the table would put the CPU about 18 bytes (12 us at 770 ns/byte) behind in the CRC/WEP/CRC calculation process. It would require about 40 data bytes to catch up (1200 clocks/30 extra clocks per byte) in both packet CRC and WEP/CRC functions. Since the minimum TCP/IP header is at least 40 bytes (plus any user data), we should have enough time. In any case if we are a little late in WEP/CRC calculation, no harm is done. An alternative approach would be to catch up first for the packet CRC calculation and then catch up with WEP/CRC.

After CRC and WEP/CRC processing, the next most critical activity is header parsing on receive and generation on transmit. This is because of the need to identify packets for the station and generate appropriate responses. On receive, the processor must parse two or three 48 bit addresses and at least a 16 bit header command field. After the packet completes, an ACK may need to be generated.

The 5402 can easily handle these functions. Since these functions are performed prior to WEP processing, the CPU has 64 instructions/byte (77—13) to perform these functions. Since many of them can be performed on a 16 bit or even 32 bit basis (the 5402 supports both 16 and 32 operations), there may be up to 128 or 256 instructions per data item (i.e. 256 instructions to perform a 32 bit address check). These functions are performed at 2 Mbit using a 1 MIPS 188 CPU. We have a 100 MIPS CPU to do the same tasks at 11 Mbit/sec.

ACK generation is likewise relatively simple. An ACK frame is only 14 bytes long, including the 4 CRC-32. Given there is a long (80 us) preamble, we have 8000 instructions to prepare the ACK. The same applies to RTS/CTS exchanges.

There are two 16 bit timers available on the 5402. In this model, one would be used for TSF timing and the other for all other functions. There are really only a few other timer functions: NAV, Retransmission, collision avoidance slot countdown, etc. Retransmission and collision avoidance activities go on only when waiting for an ACK or to start a retransmission after detection of an idle network. In such cases there is no data transfer going on and so there is lots of CPU cycles available.

Support for MU PSP function can be done in a variety of ways, depending on how much, if any, external hardware is provided. The 5402 provides a variety of means of conserving power. The first is simply to slow down the CPU clock via the software controlled PLL within the unit. The 5402 generates internal clocks via a PLL that is driven by either an external crystal or clock. The PLL multiplies the base frequency of the crystal/external clock by a factor determined by software. Hence one means of controlling power consumption is simply to slow down the CPU clock. Since the CPU portion of the processor consumes most of the power, slowing it down has the biggest affect on power consumption.

The second approach is use one of the IDLE modes of the processor. IDLE1 stops the CPU clock entirely but leaves everything else running. Power consumption in this mode is on the order of 6 mA at 100 MHz. The CPU can be restarted by any interrupt (internal or external). In IDLE2 the system clock is stopped and this reduces consumption to 2 mA. In IDLE3, all system functions are stopped and consumption is reduced to around 2 ua. In all cases all state is retained. In IDLE2 and IDLE3, an external interrupt is required to restart the CPU. In such cases an external, low power timer would be required.

Thus with no external hardware, power consumption could be reduced to at least 6 mA and perhaps less. With a simple external timer, one could get down to microamps.

The bottom line is that the vast CPU power of the 5402 allows all lower level MAC functions to be performed in software. Furthermore it has sufficient power and memory to handle additional "higher level" functions such as packet retransmission, fragmentation, and reassembly that can also be done in a cell controller.

The system **10** of the present invention is compatible with IEEE Standard 820.11 and accordingly will operate with any mobile units **20**, including existing units, which are compatible with the same standard. However, the improvements applied to the RF ports **18**, reducing the complexity and cost of these units can also be applied to the mobile units **20**, which have sufficient main processor capacity to handle the mobile unit functions corresponding to the higher order MAC functions.

Referring to FIG. **2** there is shown a block diagram for a mobile unit **20** having a mobile unit computer **22** and a WLAN adapter **24** connected thereto to provide wireless communications to the system **10** of FIG. **1**. In the mobile unit **20** of FIG. **2**, the lower level MAC functions are performed in WLAN adapter **24**, which also includes RF module **28** and antenna **29**. The configuration of WLAN adapter **24** may be similar to existing adaptors, but preferably adapter **24** is simplified to perform only the lower level MAC functions of the IEEE 802.11 protocol and allow special software **34** in host computer **22** to perform the higher level MAC functions, such as association and roaming. In a preferred arrangement the MAC functions of adapter **24** are performed in a digital signal processor **26**, as described below, which may be the same type DSP described with respect to RF port **50**.

This section addresses how the 5402 DSP could be used as a MAC engine in Mobile Unit configurations. There are two considerations in building MU WLAN solutions. The first is the location of those MAC functions, while the second is the physical interface to the host.

The location of the upper level MAC functions may vary considerably. Some possibilities are:

All functions on MAC engine DSP processor **26**

All functions on host processor **22**

Roaming/association on host processor **22**, rest on MAC engine **26**

Roaming/association/retransmission on host **22**, rest on MAC engine **26**. The choice of the location of the higher level MAC functions has a major impact on the cost of MU WLAN adapter. If one is willing to place at least some of the higher level functions on a host processor **22**, then one could get by with just the 5402 on the WLAN adapter. Possible functions to place on the host would be roaming and association control. Higher level functions such as retransmission and fragmentation/reassembly could be left on the 5402. This split would permit significant savings, since another processor/memory subsystem would not be needed on the WLAN adapter. There are two reasons for not placing all of the MAC functions on the 5402. The first is memory space on the 5402 is only 32KB of SRAM for both code and data. In some MAC implementations such as frequency hop, the code space alone exceeds 32 KB. The second reason is that the software on the 5402 is oriented toward meeting hard, real-time tasks such as CRC and WEP processing. Trying to add software intensive tasks would only complicate the process.

If another processor was required, such as an ARM or perhaps a second 5000 Series processor, the upper level functions could be added to it.

Alternatively one could place all the MAC functions on a faster and/or bigger version of the 5402 processor. Such a processor would likely have a higher clock rate (current members of the 5000 Series can be clocked as high as 160 MIPS) and more memory (say 64 KB instead of 32KB).

Both the second processor as well as a faster/bigger 5402 would consume additional power as well as adding cost.

This section will describe one approach of how a MU WLAN adapter can be arranged for various hardware host interfaces using the 5402. It assumes that enough of the upper level MAC functions have been offloaded to a host processor so that only the 5402 is required on the PLAN adapter. A second processor could be added to any of the solutions outlined below.

In all of the following solutions, it is assumed that the runtime code for the 5402 is loaded from an external source (such as computer **22**) via the host interface **32**. This eliminates the need for flash memory on the adapter card, saving several dollars in the process. It should be pointed out that the 5402 comes with 8KB of mask programmable ROM and a bootloader program (required for the USB and Ethernet host interfaces) would be placed in it. The bootloader would be smart enough to download the runtime code instructions over whatever serial interface was available.

The simplest interface of all would be for a host to use the Host Port on the 5402. This port operates as a dual port interface into the memory within the 5402. It would not be a standard interface but would be quite suitable for dedicated systems. Using it, computer **22** can read/write memory on a random or sequential basis. It is an 8 bit interface and can operate as fast as 160 Mbit/sec. When operated in random access mode, the computer **22** generates a 16 bit address using two writes to the port and then performs either a read or write operation. Such a mode allows a host to set up command blocks and the like within the memory of the 5402. Sequential mode allows a host to transfer data in and out of the 5402 memory very quickly (160 Mbit/sec). This would be used for transferring data.

If this approach was used, the only digital component on the WLAN adapter would be the 5402.

In the system of FIG. **1**, the cell controller **14** is a board level personal computer coupled to the switching hub **12** preferably by 10 M bit and 100 Mb Ethernet ports. For smaller systems a 350 MHz Pentium computer with 16 MB RAM may be used. For larger systems having many RF ports a 500 MHz Pentium with 64 MB RAM is appropriate. Communications to and from the wired network are preferably carried out at 100 MHz. Communications to and from RF ports may be carried out at 10 MHz. A second cell controller may be supplied for larger systems and/or to provide backup in the event one cell controller fails. Reliability can be enhanced by providing dual fans and dual power supplies. A flash disk memory may be used for reliability. Alternately, the cell controller **14** may be built into the switching hub **12** or into a host processor.

The operating system for the cell controller **14** may be a real time operating system, such as VRTX or QNX, which provides multitasking, a full network stack and utilities. Web based management utilities, which are client side java based, are provided for maintaining the configuration of the cell controller **14**, the RF ports **18** and status of the mobile units **20**.

The cell controller **14** includes applications to provide mobile unit association management, roaming and packet

buffer management. These applications are similar to those performed by current access points in the Spectrum 24 system. The cell controller **14** may also provide QoS support, user authorization and configuration management. Placing these functions on a personal computer cell controller facilitates system management and program updates using available programming tools. Further, modifications to authorization or management functions need only be installed into the cell controller **14**, and no modification to the software of the RF ports **18** is required.

The cell controllers **14** handle routing of all messages to or from the mobile unit. The cell controller buffers message packets received from the wired network and determines the appropriate RF port **18** with which the addressed mobile unit **20** is associated and sends the packet to the RF port **18**. The cell controller **14** can additionally perform WEP encryption/decryption and the CAC associated therewith.

The cell controller **14** may also the additional function of maintaining and downloading firmware to the RF ports **18**. Upon power up the RF ports **18** use a bootloader routine stored in ROM to send a download request to cell controller **14**. The cell controller then downloads firmware to the RF port **18**, including configuration information such as channel assignment, ESS and BSS identification. The cell controller **14** and RF ports **18** additionally share a common TSF clock.

The mobile unit computer **22** of mobile unit **20** is provided with similar software to perform the higher level MAC functions as outlined above. Advantageously, the software **34** can be programmed using the same operating system as provided for the computer, and thereby provide a user interface, such as Windows, which is familiar to the user. The mobile unit software **34** provides the MAC functions of header building, roaming and association. The mobile unit computer **22** may also download firmware to the processor in the WLAN adapter **24**.

As evident from the forgoing description, the hardware for RF port **18** and WLAN adapter **24** of mobile unit **20** can be substantially similar, with the possible exception of the interface to an Ethernet network or to a mobile unit host. Further, the logical cell controller function and the higher order MAC functions performed by the mobile unit host processor can be performed on any computer system.

Using the RF port **18** of the present invention coupled to a computer system, it is possible to provide either a mobile unit or a wireless network according to the software provided. Since the software for RF port **18** may be downloaded from a host system a simple combination of a computer and one or more RF ports can function as either a WLAN mobile unit as a WLAN host or both, by providing function selectable firmware to the processor in the RF port.

In the arrangement shown in FIG. **5**, a personal computer **70** is provided with software **72** and connected to one or more RF ports **50**A, **50**B to provide a complete host system for wireless data communications. This arrangement could be used, for example, in a small business wherein office equipment is connected to server **70** by a wired network for conventional LAN operation and one or more RF ports **50** are also connected to server **70** on the LAN system to provide data communications between the server **70** and mobile units. The server can perform the higher order MAC functions and download firmware instructions to the RF ports. Alternatively, the firmware instructions can be installed on PROM memory in the RF ports.

FIG. **6** shows an arrangement for providing wireless access to the Internet using the RF port **50** of the present invention. Internet access over communications line **80** to modem **82** may be provided by cable, DSL or fiber optical transmission. RF port **50** may be provided with MAC firmware on PROM or may be configured with a bootloader

program to download firmware from an ISP server. When installed in a home or office, mobile units **20** can associate with RF port **50** to initiate Internet access. The ISP server may perform the higher level MAC function, or they may be provided in RF port **50**.

The mobile units **20** may be the personal computers **22** in a home or office with a WLAN adapter **24** as shown in FIG. **2**.

FIG. **7** illustrates an example of communications formats that might be used in the various system embodiments of the present invention. The FIG. **7** example assumes that the configuration includes a host **90** connected to a dedicated cell controller **14**, which is likewise connected to RF port **18**. It should be clearly understood that the logical cell controller functions may be performed in host **90**, particularly in a simple system.

In the FIG. **7** example host **90** sends message “A” having 100 data bytes via an Ethernet packet **100** to cell controller **14**. Packet **100** has a destination address of the Mobile unit (M1), a source address of the host (H) and includes data (A). Cell controller **14** formats the data in 802.11 format with the destination corresponding to mobile unit (MU1) **20**. The cell encapsulates this 802.11 packet with data A into an Ethernet packet **104** addressed to RF port **1** (RF1) from the cell controller (cell controller).

RF port **18** receives the Ethernet packet **104** from cell controller **14** and generates and sends an RF packet **112** in 802.11 format to mobile unit **20**, including data A. It should be understood that 802.11 header generation can be provided at either the cell controller **14** or the RF port **18**, but packet **104** must include mobile unit identification data either as an 802.11 header or otherwise to enable RF port **18** to generate the header. RF port **18** additionally performs the CRC computation and adds the result to the 802.11 packet **112**.

A second message “B” having 1500 bytes of data is also shown as originating as Ethernet packet **102** from host **90** to cell controller **14**. Cell controller fragments data message B into three fragments B**1**, B**2** and B**3** to accommodate the 500 byte data limit of 802.11 packets. These three fragments are sent as Ethernet packets **106**, **108**, **110** to RF port **18**, which transmits RF signal packets **114**, **116**, **118** to mobile unit **20**.

Reverse communication is similar. Message C has 100 bytes and is sent by mobile unit **20** to RF port **18** as 802.11 RF signal packet **200**. RF port **18** encapsulates this message into Ethernet packet **208** and sends it to cell controller **14**, which extracts the destination information and data to provide Ethernet message **216** to the host **90**. A larger message D is sent as message fragments **202**, **204**, **206** to RF ports **18**, relayed as Ethernet packets **210**, **212**, **214** to cell controller **14** and sent as a reassembled Ethernet packet **218** to host **90**.

Referring now to FIG. **8**, shown is an application of the central controller/RF port model that may be used to set multiple overlapping ESS LANs for use in the same or overlapping physical space. Shown in FIG. **8** is a central controller **260** which is associated with two RF ports, RF port **1 250** and RF port **2 270**. The central controller **260** may be associated with more than two RF ports, but two are shown for illustration purposes. Each RF port **250**, **270** provides coverage for a wireless LAN in the physical areas **240**, **310**.

FIG. **8** further illustrates the concept of providing multiple ESS identifications through the same RF port and cell controller such that each ESS identification is associated with a separate virtual wireless local area network having its own policies and security. Thus, RF port **1 250** may be configured so as to support separate BSS networks 1A **230**, 1B **220** and 1C **210**, all of which occupy the same physical space **240**. The RF port may support more than three BSS networks, but three are shown for illustration purposes. Similarly, RF port **2 270** may be configured so as to support

BSS networks **2**A **300**, **2**B **290** and **2**C **280**, all of which occupy the same physical space **310**. Using the configuration as shown in FIG. **8**, multiple ESS LANs may be coordinated by the central controller **260** in the physical space **240** and **310**. ESS A personnel, such as airport employees, may have access to the public level and also have access to the airport operational network. The security-based network would be available for select airport personnel such as management and security officers.

The cell controller performs the function of determining which ESS network a mobile unit communicating with an RF port associated with the cell controller is operating on, and thereby controls the direction of communication from the cell controller to the network. The cell controller can verify the multiple levels of security provided in connection with the access by the mobile unit devices, and in addition can prioritize communications so that higher priority communications such as security communications are given greater access to the system during higher traffic conditions. For example, in the three-tier embodiment discussed above, the security network could have a feature to disallow all other network access in an emergency situation.

A similar multi-virtual LAN network may be also useful in a health care facility wherein different networks are used for security, medical care, personal and public information.

The architecture described herein offers advantages in several discrete areas of wireless network management.

Bandwidth Management

An aspect of functionality that can be realized in connection with the configuration described herein is to modify the bandwidth of communications in accordance with the type of device with which the communication is associated. For example, where a data set comprises an image, for example retrieved from the Internet, the resolution of the image can be modified in the cell controller to accommodate the resolution capacity of a portable device. Therefore, rather than provide a highly detailed image of the type that can be displayed on a personal computer, an image-bearing message can be reduced in resolution in the cell controller to a lower resolution, compatible with a portable device, such as a personal digital assistant. By therefore reducing the resolution of the image being sent, the bandwidth and data capacity necessary to send the image can be significantly reduced.

Another functionality available with the configuration described herein is to control the individual RF ports according to the traffic experienced by the system. For example, the cell controller can assigned an RF port experiencing a high volume of communication to a different channel, such as a reserve channel on which no other RF ports are operating. This will minimize interference in communications conducted with a particular RF port that is experiencing high volume. In this manner the RF port may be the only RF port operating on the particular, reserve channel. The cell controller has real time information available to it in order to make the changes in the RF port configuration to accommodate changing load conditions.

A wireless system may also contain RF ports sending and receiving overlapping 2.4 GHz, Bluetooth, and 5 GHz signals. These signals will have differing frequencies, power levels, and data rates. Because the cell controller will monitor all features of the frequencies generated by the RF ports and will know the locations of the RF ports, the cell controller will have the ability to optimize the frequency, power level and data rates in the physical space for the best possible performance.

The cell controller provides a central location for interfacing the WLAN with WAN features that may be accessed by users. For example, the cell controller can coordinate the processing necessary to enable voice over IP (VoIP), i.e. compression or user allocations. Compression is particularly enhanced using a cell controller because the cell controller can maintain the necessary historical dictionaries needed for efficient compression algorithms in one location that applies to all RF ports. The cell controller can also proxy to access a SIM database for WAN users in advance of actually needing this data to perform operations.

The cell controller allows additional functionality to the WLAN at all levels while maintaining the compatibility in the MAC level necessary for IEEE 802.11 systems. One such example would network management features that are not present in the 802.11 protocol but would be useful to operate at the cell controller/RF port level. An embodiment of this is to monitor the software versions present in the MUs in a WLAN and send out updated versions when each MU "checks in" with the cell controller. Ultimately this allows the costs of APs/RF ports to remain relatively inexpensive.

Other aspects of routing traffic through the cell controller is the ability to detect interference and noise and the ability to control the transmit power of particular RF ports. For example, the cell controller can command the RF port to provide the signal level they are receiving when there is no communication (background noise or interference) to the cell controller. This can be used to provide an analysis of the system operation or to provide the detection of background interference and its location.

Security

Another available function of this architecture is control of association, since all association is handled in a cell controller. Accordingly, where a "public access only" device attempts to associate with the system in a secure area such as, for example, an airport control tower, where a member of the public should not be, the fact of this association attempt can be noted in the cell controller and automatically give notice to security personnel. The cell controller can additionally deny or permit access to a mobile unit attempting to associate with an RF port according to traffic at the RF port as observed at the cell controller. The cell controller thereby has a measure of control over roaming and can command a mobile unit as to which RF port to become associated with. Indeed, under many WLAN architectures, APs do not coordinate with each other to determine if they are being probed in such a way that an attempt to break security may be occurring. In contrast, a cell controller can monitor all such probing to determine if an attack may be taking place. Logs of such probing may be kept. In addition, authentication protocols may be centralized in the cell controller instead of on a central server, creating greater efficiency.

Another important aspect of control of association and roaming in the cell controller is the fact that the cell controller can perform a "soft-roaming" function. Soft-roaming takes place when the cell controller changes ownership of the BSS identification between RF units. In essence the cell controller has the ability to tell a mobile unit which RF port it will communicate through. In connection with doing so it is possible for one RF port to monitor traffic to another RF port and thereby advise the cell controller that it has the capability of receiving signals from that particular mobile unit. The cell controller has the ability to control the access of the mobile units to RF ports according to traffic as observed in the cell controller. One aspect of the system is that the intelligence in the cell controller interacts with the intelligence in the mobile unit to control association. The RF port has no part in this and accordingly there is a greater ability to centrally managed the flow of traffic through the RF port. Another aspect is to provide an arrangement in the cell controller wherein only one RF port can perform secure data communication. When a mobile unit desires a secure link, the cell controller can switch the mobile unit to a particular RF port for secure communications. In essence the

unit is capable of providing a virtual RF port. The switching of the BSS identification between RF ports takes place in the cell controller and the mobile unit has no idea that it has been given the bait and switch. Another aspect of the centralized management is security, in that if a mobile unit which does not have access authorization attempts a number of times to gain access to the system, the security program in the cell controller can provide an alert and in essence lock out further attempts by that mobile unit.

Location Tracking

In the architecture described herein, because RF ports are cheaper than typical APs, there may be more RF ports in a given area than APs. This proliferation of RF ports will allow location tracking to take place. Moreover, one RF port has the ability to "snoop" and listen in to the traffic between another RF port and a mobile unit. The cell controller can take all this data in and use time stamping based on the arrival of data. Such information can be passed through the Ethernet to a processor that can determine location.

Diagnostic Capability

An important capability which the cell controller can also implement is the diagnostic capability. As an initial calibration when a system is first brought into operation the cell controller can cause the RF ports to go through a sequence in which the RF ports communicate to each other. In this way the signal level of each RF port, as observed at one or more other RF ports, can be monitored and the radio location of the RF ports can be mapped, for example, to create alternative RF ports to which traffic can be switched in the event of excess traffic on any particular RF port. Accordingly using RF signals the cell controller can dynamically discover the RF locations and signal characteristics between RF ports. Each RF port in this case would provide the cell controller with an indication of the strength of the signals received. The cell controller can also record the background noise level. Following the initial calibration of the system the cell controller can undertake periodic diagnostics, wherein signals are sent from one RF port to another and the signal level is relayed to the cell controller to determine whether if the transmitters and receivers are operating properly. In this respect, the signals received can be compared to the base line signal levels which have been recorded at the cell controller as a calibration level. Changes in background noise can also be determined and this can be used to detect a problem with a receiver in the system.

While there has been described what is believed to be claimed in the above-identified application those skilled in the art will recognize that other and further modifications may be made without departing from the scope of the invention and it is intended to claim all such changes and modifications as fall within the true scope of the invention.

I claim:

1. A system for providing wireless data communications between mobile units and a wired network operating according to a wireless data communications standard protocol having high level MAC functions and low level MAC functions, comprising:

a plurality of RF ports configured to perform the low level MAC functions of the wireless data communications standard protocol, the RF ports having at least one data interface and a security status, said RF ports being arranged to receive formatted data signals at said data interface and transmit corresponding RF data signals and arranged to receive RF data signals and provide corresponding formatted data signals; and

at least one cell controller separately housed from said plurality of RF ports and configured to perform the high level MAC functions of the wireless data communications standard protocol, the at least one controller arranged to receive data signals from said wired network and to provide formatted data signals corresponding thereto to said data interface of said RF ports and to receive formatted data signals from said RF ports and to provide data signals corresponding thereto to said wired network, said cell controller controlling association of mobile units with one of said RF ports based on the security status of the one of said RF ports, providing formatted data signals for said mobile units to an associated RF port, and receiving formatted data signals from said mobile unit from said associated RF port.

2. The system specified in claim **1** wherein the wireless data communications standard protocol is the IEEE 802.11 standard protocol.

3. The system specified in claim **1**, wherein said low level media access control functions performed by said RF ports include a cyclic redundancy check function.

4. The system specified in claim **1**, wherein said low level media access control functions performed by said RF ports include a network activity vector function.

5. The system specified in claim **1**, wherein said low level media access control functions performed by said RF ports include a ready to send/clear to send function.

6. The system specified in claim **1**, wherein said low level media access control functions performed by said RF ports include a header generation/parsing function.

7. The system specified in claim **1**, wherein said low level media access control functions performed by said RF ports include a collision avoidance function.

8. The system specified in claim **1**, wherein said low level media access control functions performed by said RF ports include a frequency hopping function.

9. The system specified in claim **1**, wherein said low level media access control functions performed by said RF ports include an ack parsing/generating function.

10. The system specified in claim **1**, wherein said lower level media access control functions performed by said RF ports include a retransmission timeout function.

11. The system specified in claim **1**, wherein said higher level media access control functions performed by said cell controller include a roaming function.

12. The system specified in claim **1**, wherein said higher level media access control functions performed by said cell controller include a retransmission function.

13. The system specified in claim **1**, wherein said higher level media access control functions performed by said cell controller include a rate control function.

14. The system specified in claim **1**, wherein said higher level media access control functions performed by said cell controller include a host interface function.

15. The system specified in claim **1**, wherein said lower level media access control functions performed by said RF ports includes a cyclic redundancy check function, a network activity vector function, a ready to send/clear to send function, a header generation/parsing function, a collision avoidance function, a frequency hopping function, an ack parsing/generating function, and a retransmission timeout function.

16. The system specified in claim **1**, wherein said higher level media access control functions performed by said cell controller include a roaming function, a retransmission function, a rate control function, a host interface function.

* * * * *

EXHIBIT C

US006625454B1

(12) **United States Patent**
Rappaport et al.

(10) **Patent No.: US 6,625,454 B1**
(45) **Date of Patent: *Sep. 23, 2003**

(54) **METHOD AND SYSTEM FOR DESIGNING OR DEPLOYING A COMMUNICATIONS NETWORK WHICH CONSIDERS FREQUENCY DEPENDENT EFFECTS**

(75) Inventors: **Theodore Rappaport**, Salem, VA (US); **Roger Skidmore**, Blacksburg, VA (US); **Eric Reifsneider**, Blacksburg, VA (US)

(73) Assignee: **Wireless Valley Communications, Inc.**, Austin, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 299 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **09/633,121**

(22) Filed: **Aug. 4, 2000**

(51) **Int. Cl.**[7] **H04B 17/00**

(52) **U.S. Cl.** **455/446**; 455/422; 455/423; 455/424; 455/425; 455/67.1; 703/21; 703/22

(58) **Field of Search** 455/560, 561, 455/422, 423, 424, 425, 446, 67.1; 703/2–4, 21, 22

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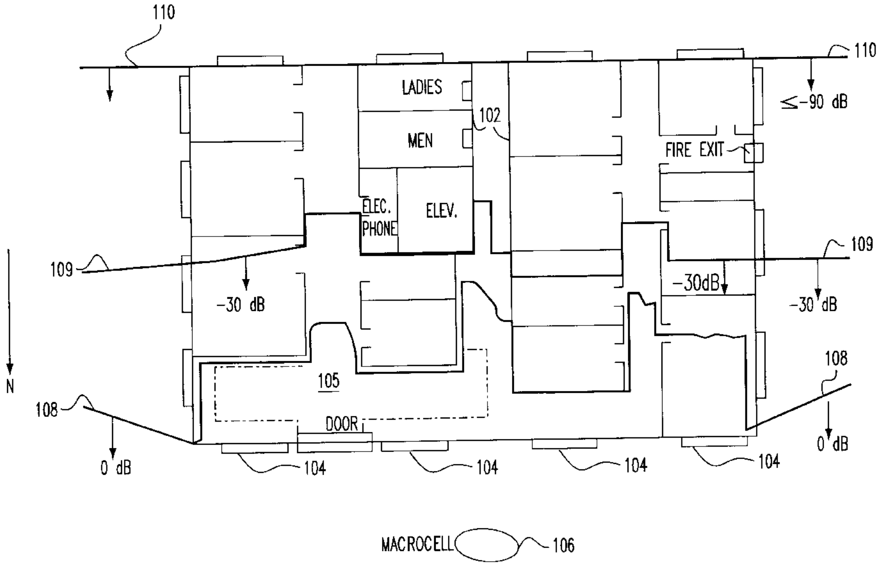
Primary Examiner—William Trost
Assistant Examiner—Earl Moorman
(74) *Attorney, Agent, or Firm*—Whitham, Curtis & Christofferson, PC

(57) **ABSTRACT**

A computerized model provides a display of a physical environment in which a communications network is or will be installed. The communications network is comprised of several components, each of which are selected by the design engineer and which are represented in the display. Errors in the selection of certain selected components for the communications network are identified by their attributes or frequency characteristics as well as by their interconnection compatibility for a particular design. The effects of changes in frequency on component performance are modeled and the results are displayed to the design engineer. A bill of materials is automatically checked for faults and generated for the design system and provided to the design engineer. For ease of design, the design engineer can cluster several different preferred components into component kits, and then select these component kits for use in the design or deployment process.

14 Claims, 22 Drawing Sheets



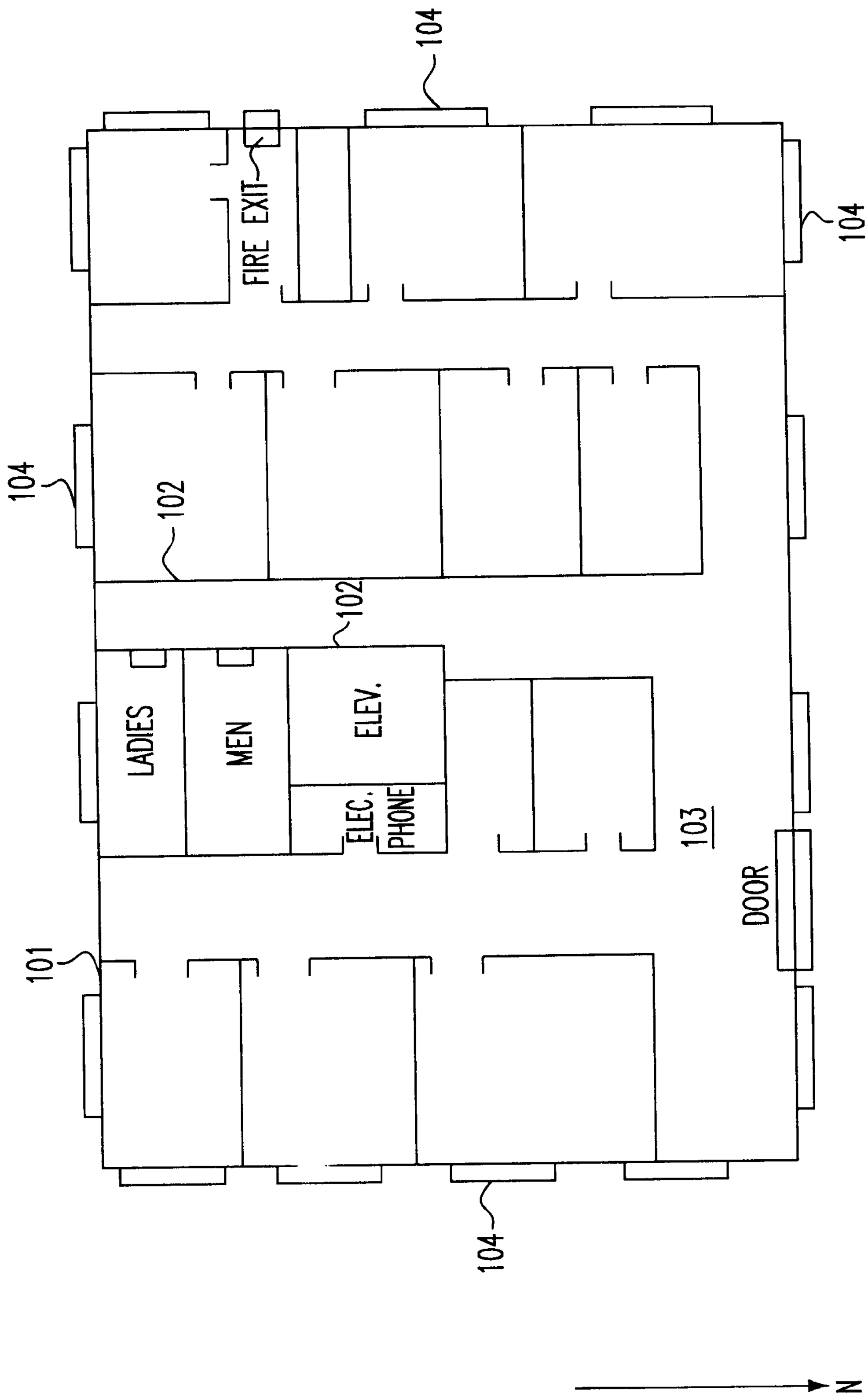

104
FIRE EXIT
104
104
102
102
LADIES
MEN
ELEV.
ELEC.
PHONE
103
DOOR
101
104
N

FIG. 1

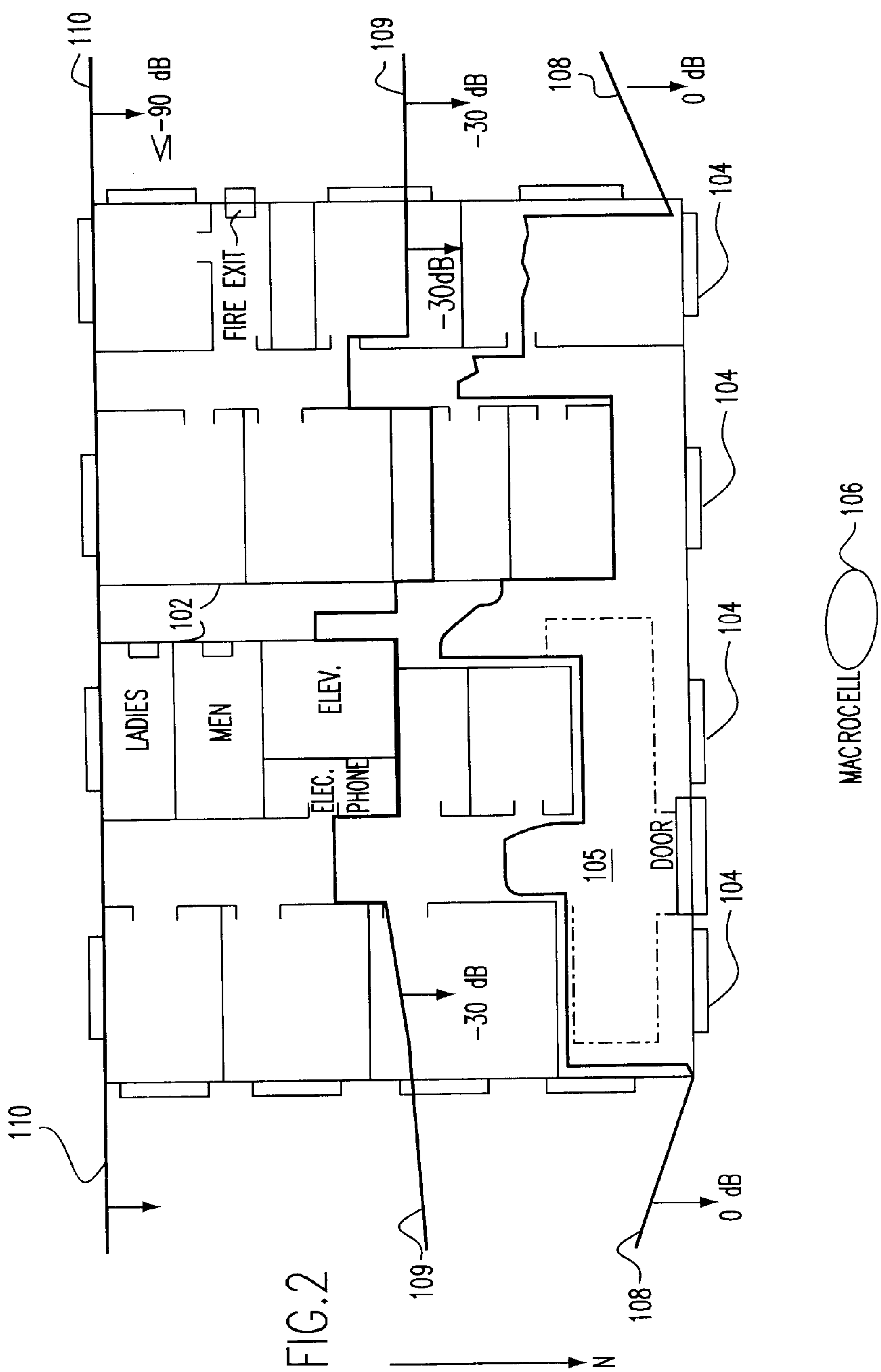

110
≤ -90 dB
109
-30 dB
108
0 dB
104
FIRE EXIT
-30dB
106
MACROCELL
102
LADIES
MEN
ELEV.
ELEC.
PHONE
DOOR
105
-30 dB
N

FIG. 2

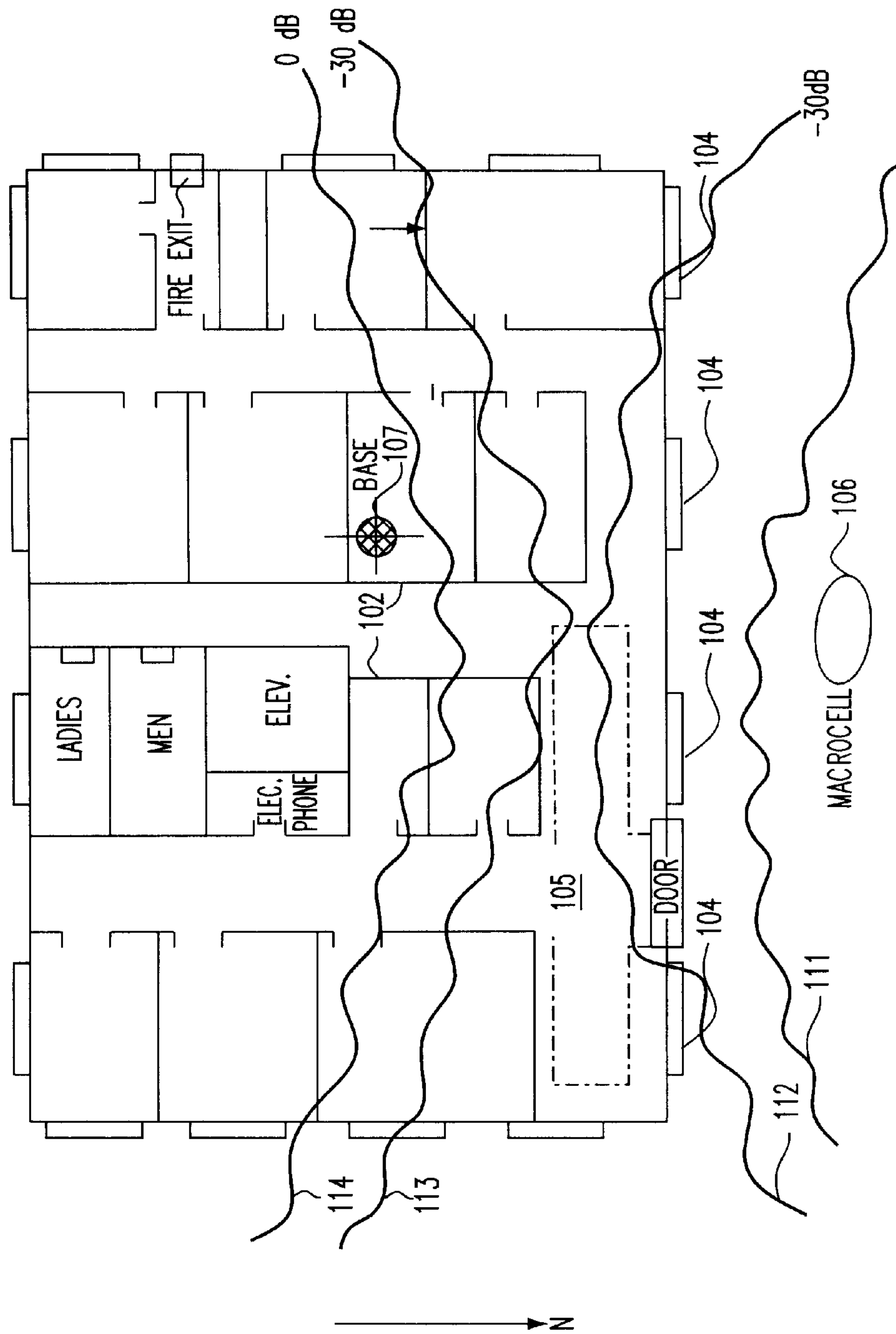

0 dB
−30 dB
−30dB
0 dB
FIRE EXIT
104
104
104
104
BASE
107
102
LADIES
MEN
ELEV.
ELEC.
PHONE
105
DOOR
106
MACROCELL
111
112
114
113
N

FIG.3

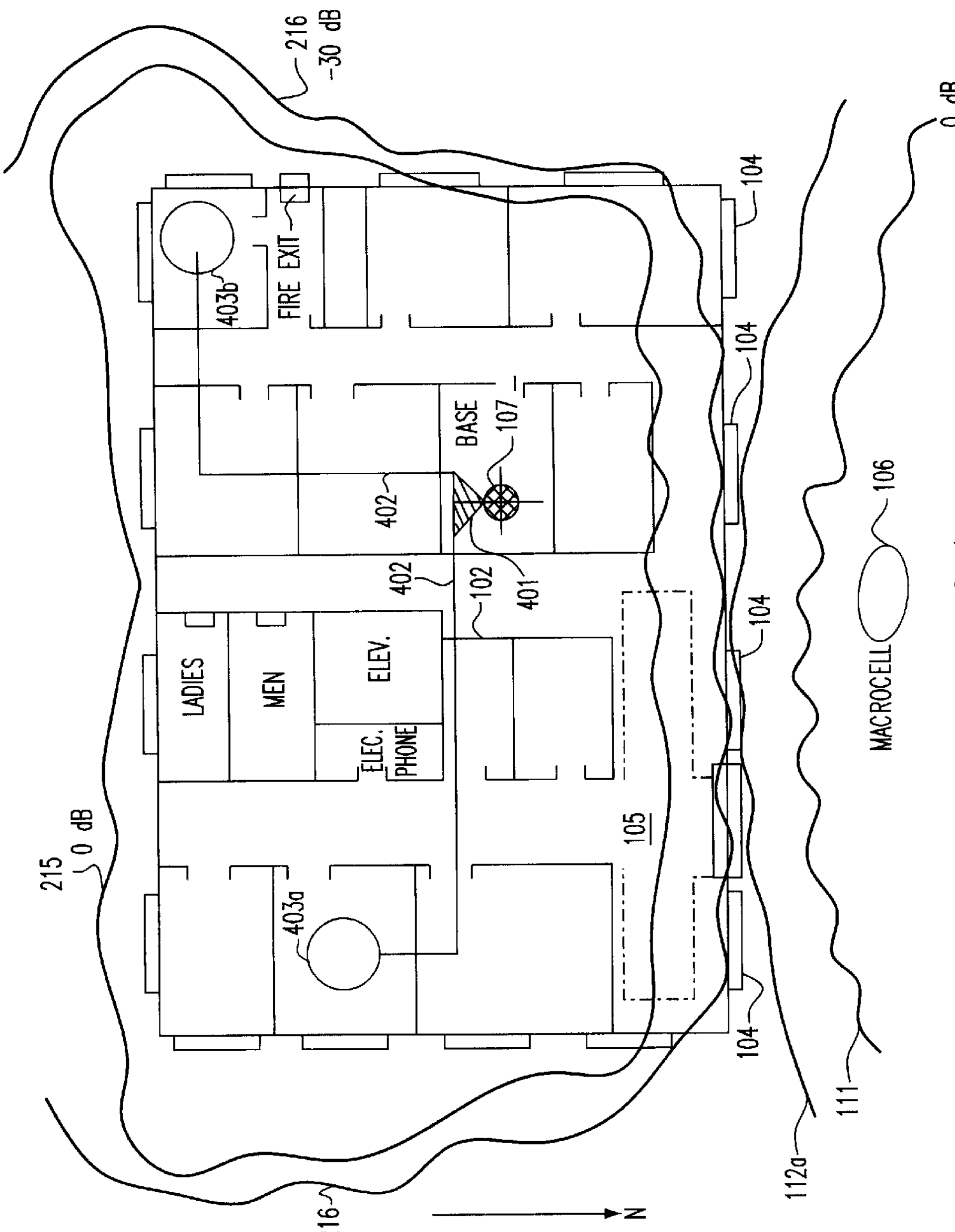
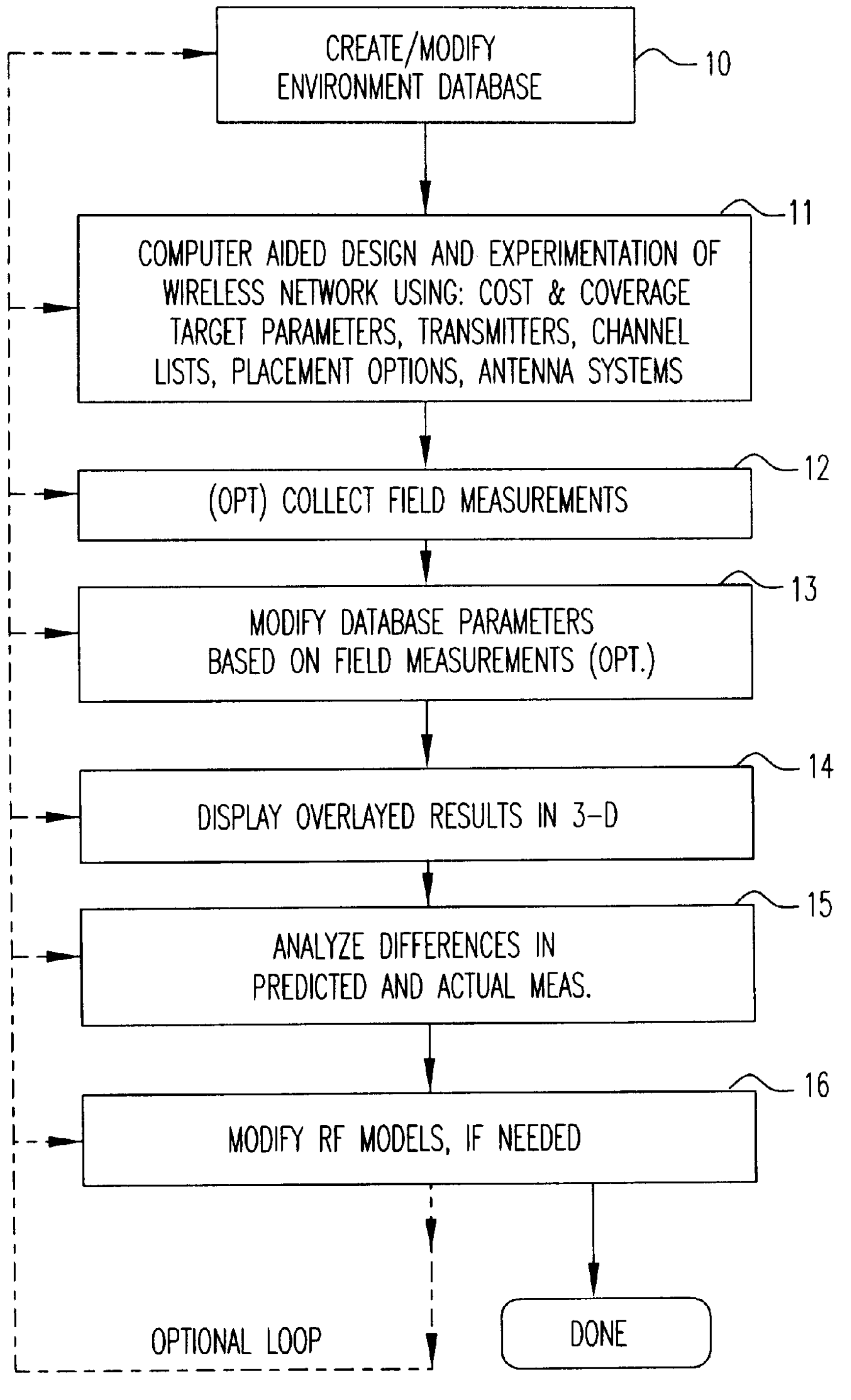

216
-30 dB
0 dB
104
FIRE EXIT
403b
BASE
107
402
401
102
LADIES
MEN
ELEV.
ELEC.
PHONE
105
403a
215
0 dB
216
N
112a
111
MACROCELL
106

FIG. 4



CREATE/MODIFY ENVIRONMENT DATABASE
10
COMPUTER AIDED DESIGN AND EXPERIMENTATION OF WIRELESS NETWORK USING: COST & COVERAGE TARGET PARAMETERS, TRANSMITTERS, CHANNEL LISTS, PLACEMENT OPTIONS, ANTENNA SYSTEMS
11
(OPT) COLLECT FIELD MEASUREMENTS
12
MODIFY DATABASE PARAMETERS BASED ON FIELD MEASUREMENTS (OPT.)
13
DISPLAY OVERLAYED RESULTS IN 3-D
14
ANALYZE DIFFERENCES IN PREDICTED AND ACTUAL MEAS.
15
MODIFY RF MODELS, IF NEEDED
16
OPTIONAL LOOP
DONE

FIG.5

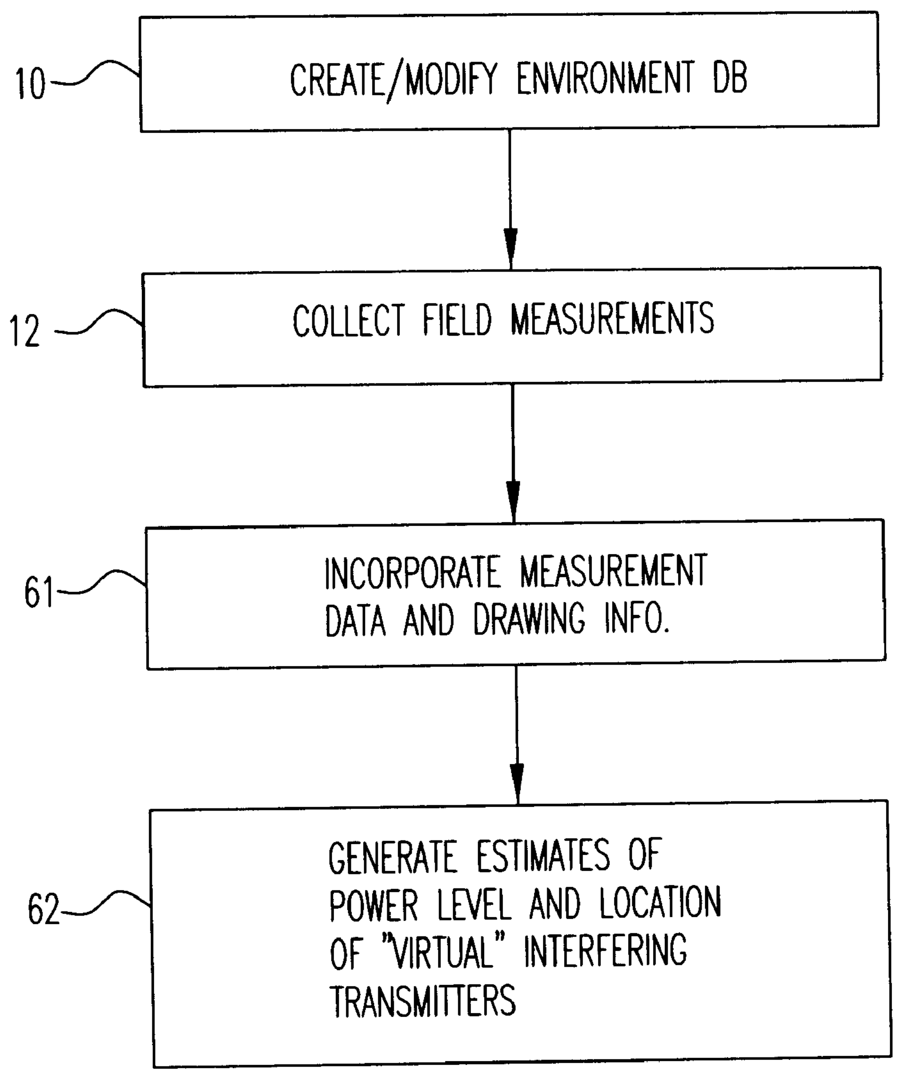

10
CREATE/MODIFY ENVIRONMENT DB
12
COLLECT FIELD MEASUREMENTS
61
INCORPORATE MEASUREMENT DATA AND DRAWING INFO.
62
GENERATE ESTIMATES OF POWER LEVEL AND LOCATION OF "VIRTUAL" INTERFERING TRANSMITTERS

FIG.6

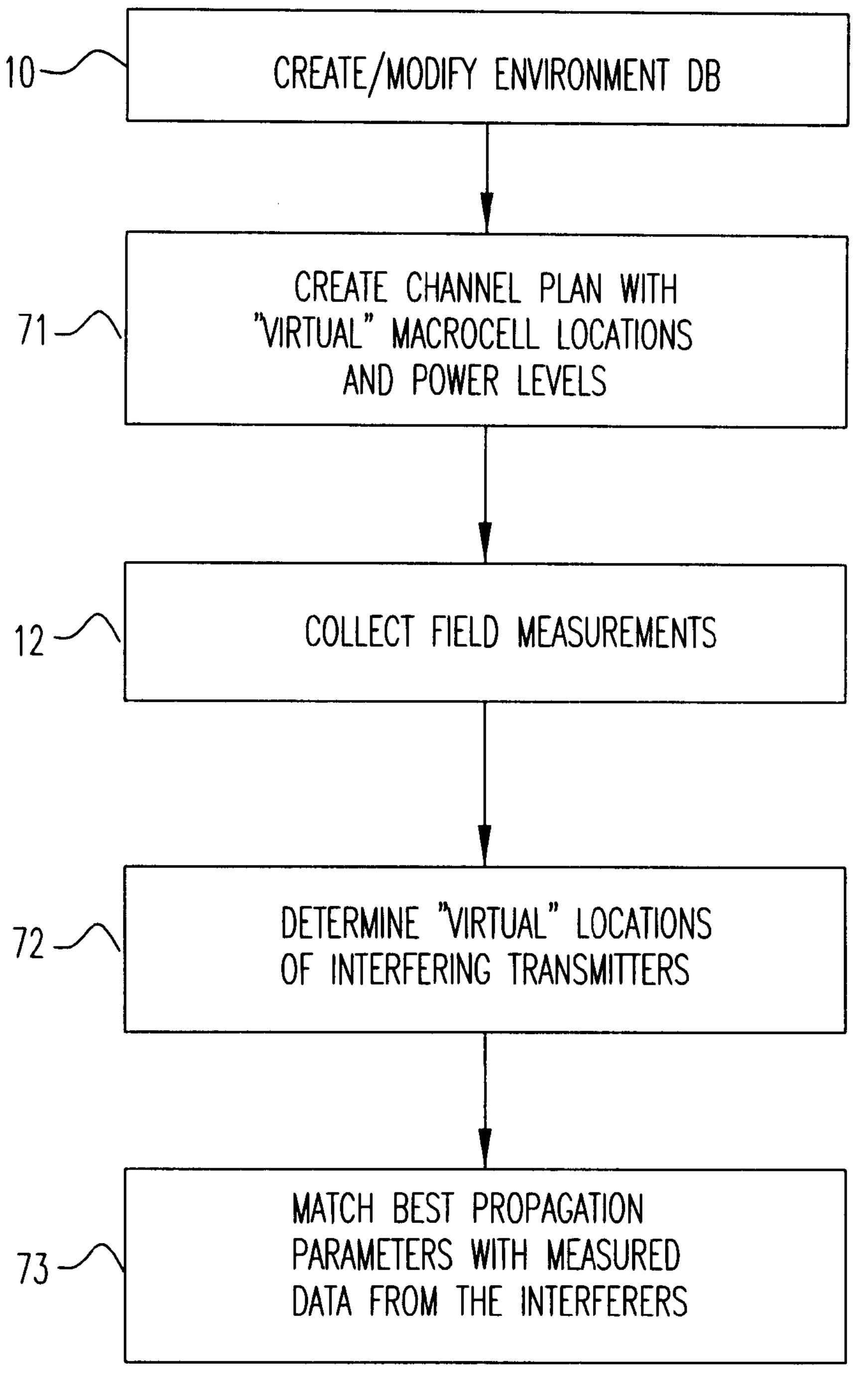

10
CREATE/MODIFY ENVIRONMENT DB
71
CREATE CHANNEL PLAN WITH "VIRTUAL" MACROCELL LOCATIONS AND POWER LEVELS
12
COLLECT FIELD MEASUREMENTS
72
DETERMINE "VIRTUAL" LOCATIONS OF INTERFERING TRANSMITTERS
73
MATCH BEST PROPAGATION PARAMETERS WITH MEASURED DATA FROM THE INTERFERERS

FIG.7

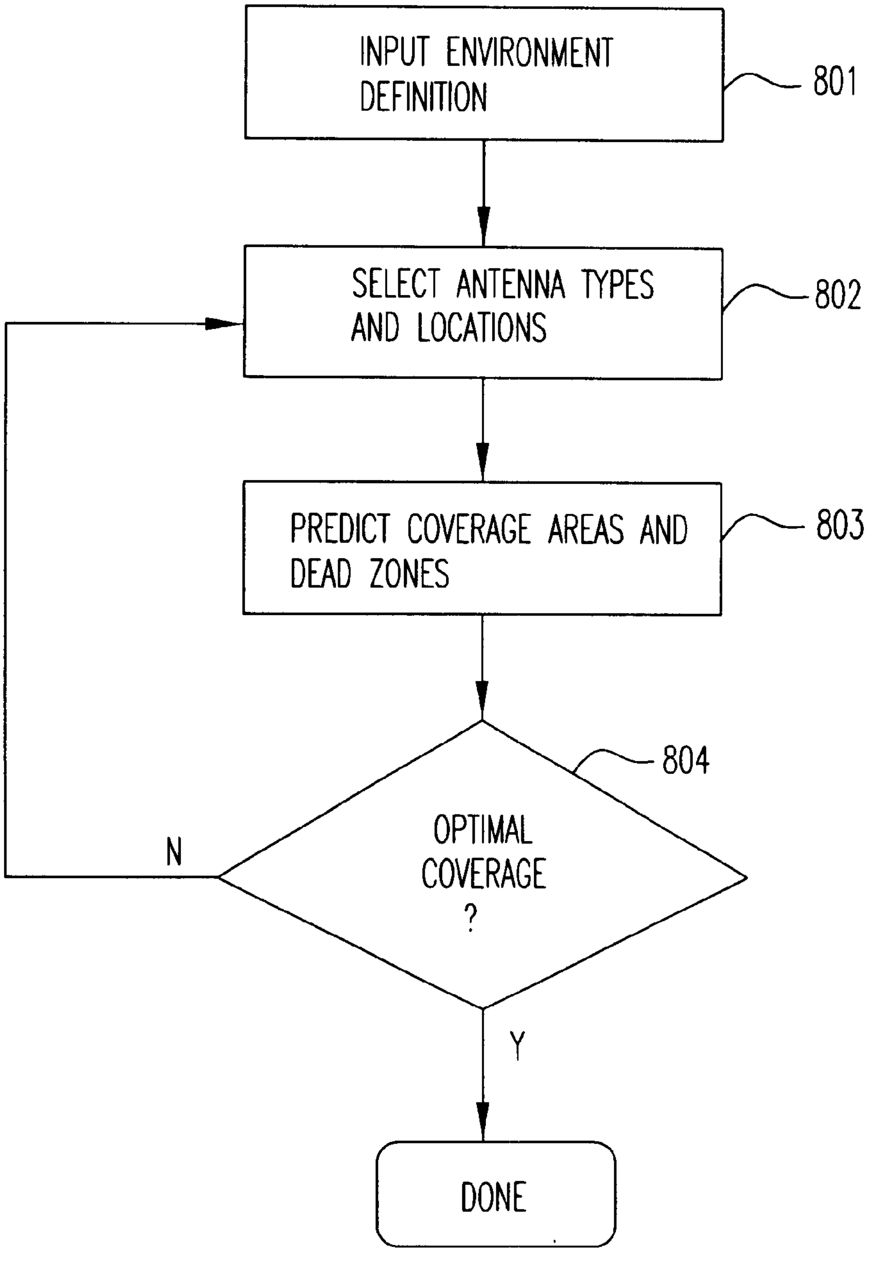

INPUT ENVIRONMENT DEFINITION
801
SELECT ANTENNA TYPES AND LOCATIONS
802
PREDICT COVERAGE AREAS AND DEAD ZONES
803
804
OPTIMAL COVERAGE ?
N
Y
DONE

FIG.8

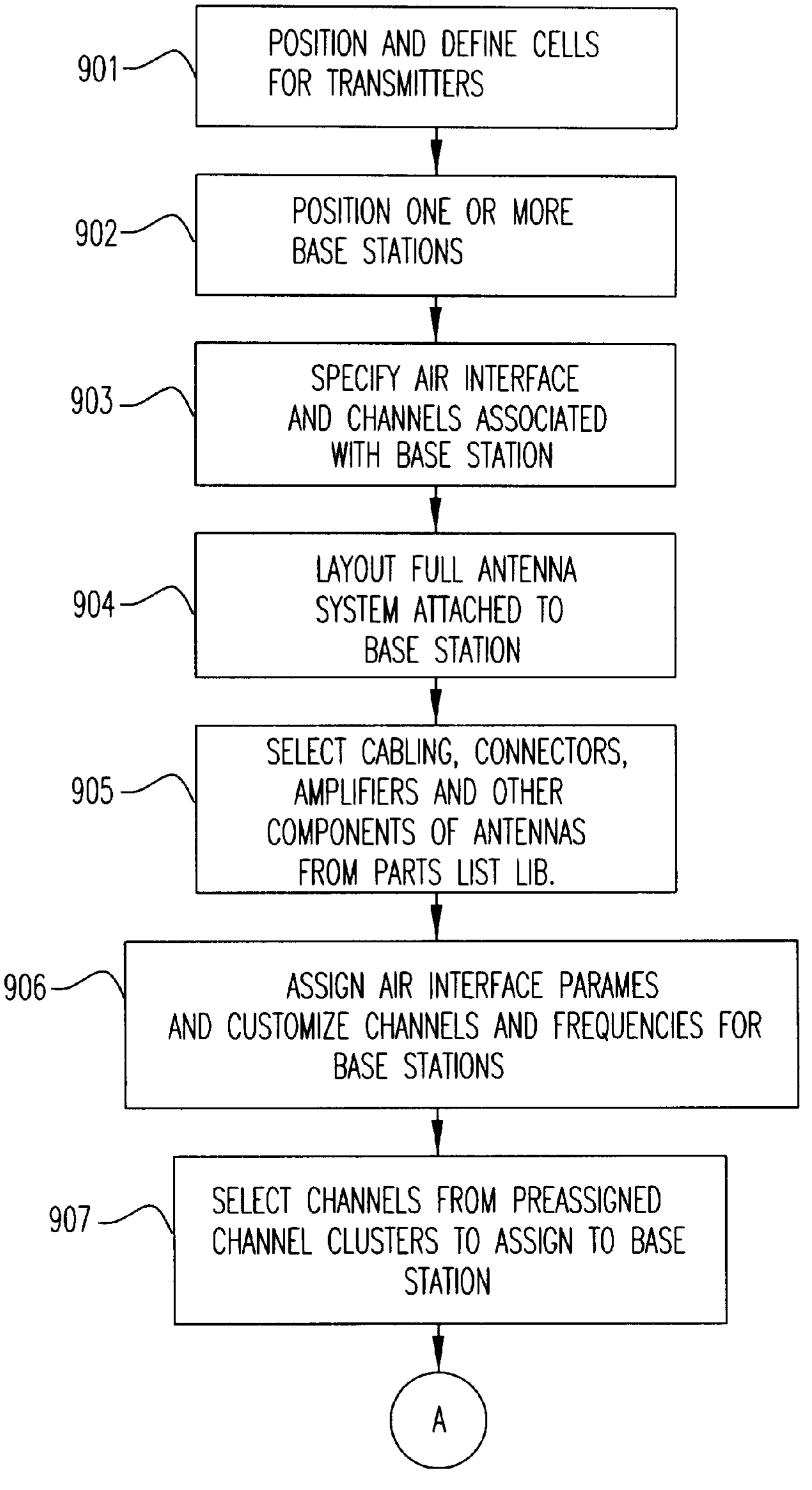

901
POSITION AND DEFINE CELLS FOR TRANSMITTERS
902
POSITION ONE OR MORE BASE STATIONS
903
SPECIFY AIR INTERFACE AND CHANNELS ASSOCIATED WITH BASE STATION
904
LAYOUT FULL ANTENNA SYSTEM ATTACHED TO BASE STATION
905
SELECT CABLING, CONNECTORS, AMPLIFIERS AND OTHER COMPONENTS OF ANTENNAS FROM PARTS LIST LIB.
906
ASSIGN AIR INTERFACE PARAMES AND CUSTOMIZE CHANNELS AND FREQUENCIES FOR BASE STATIONS
907
SELECT CHANNELS FROM PREASSIGNED CHANNEL CLUSTERS TO ASSIGN TO BASE STATION
A

FIG.9A

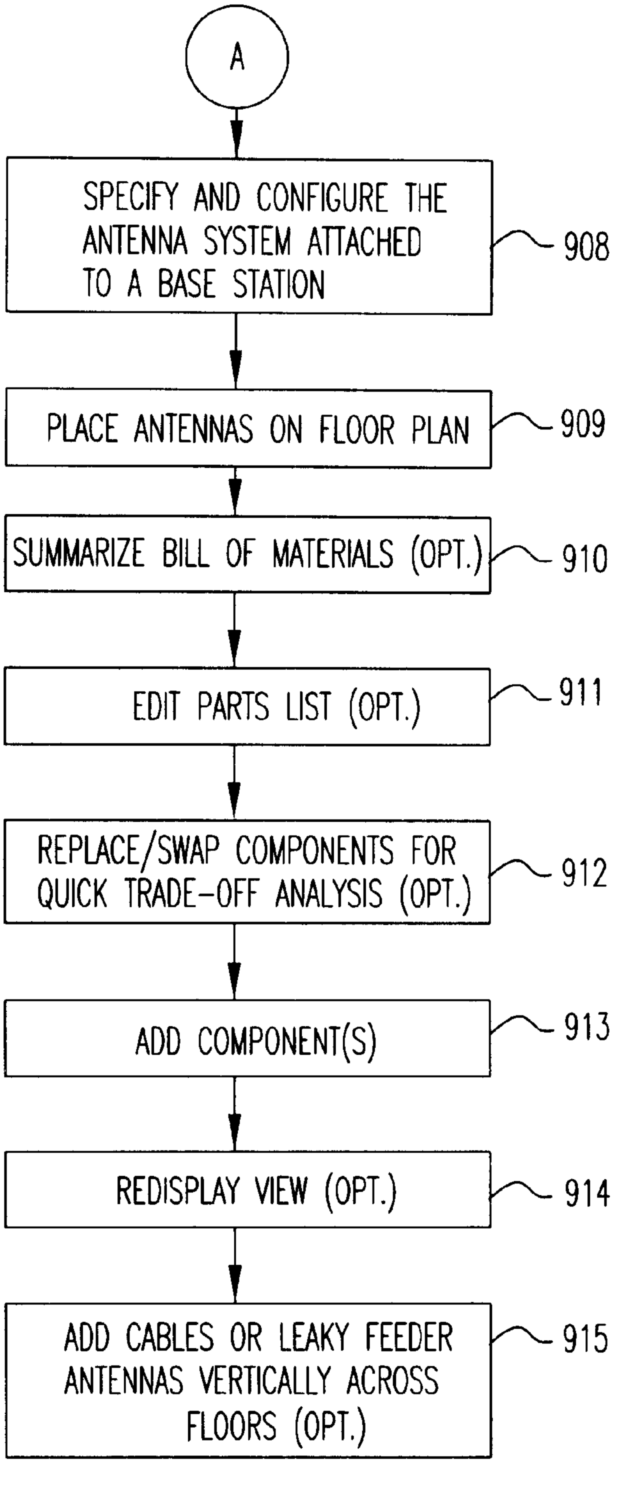

A
SPECIFY AND CONFIGURE THE ANTENNA SYSTEM ATTACHED TO A BASE STATION
908
PLACE ANTENNAS ON FLOOR PLAN
909
SUMMARIZE BILL OF MATERIALS (OPT.)
910
EDIT PARTS LIST (OPT.)
911
REPLACE/SWAP COMPONENTS FOR QUICK TRADE-OFF ANALYSIS (OPT.)
912
ADD COMPONENT(S)
913
REDISPLAY VIEW (OPT.)
914
ADD CABLES OR LEAKY FEEDER ANTENNAS VERTICALLY ACROSS FLOORS (OPT.)
915

FIG.9B

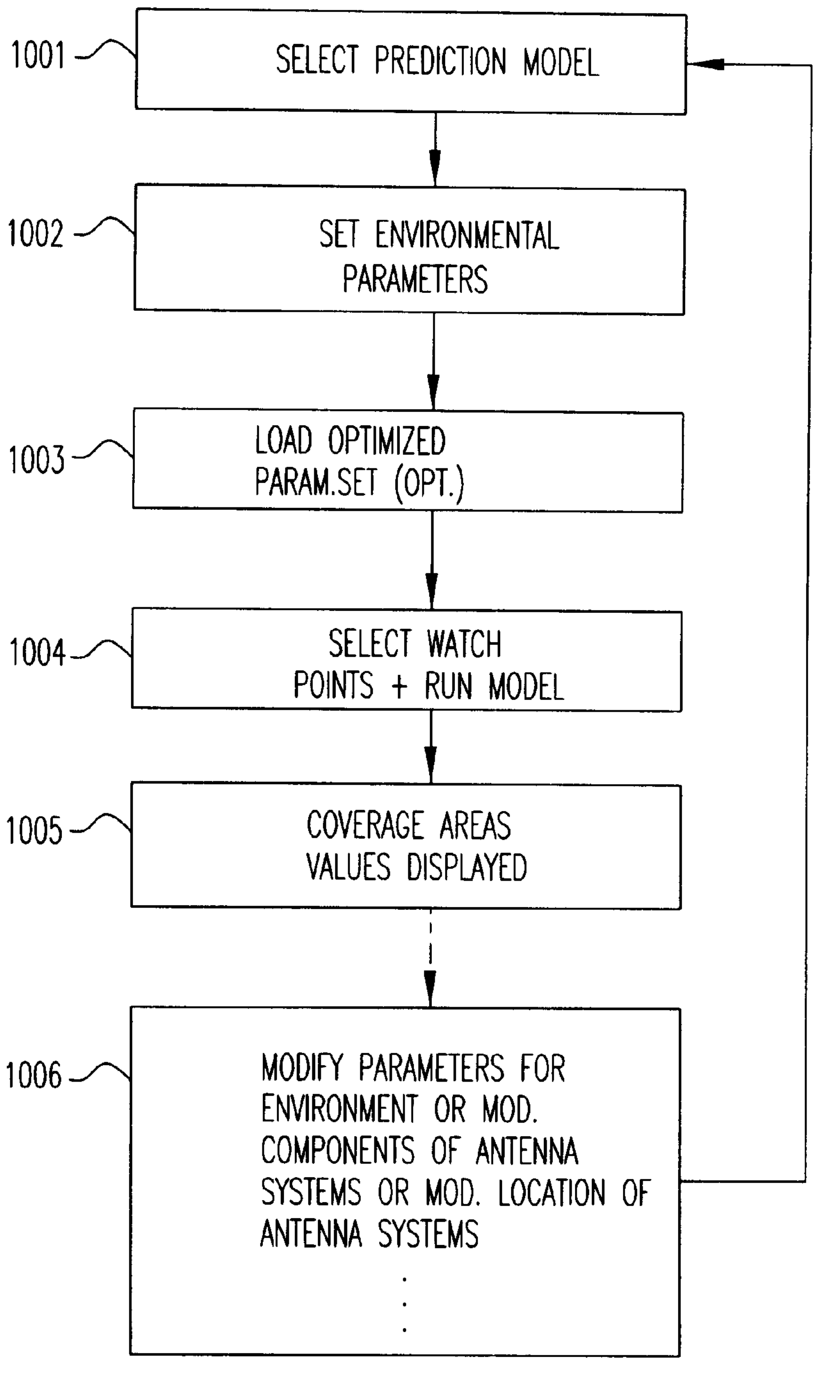

1001
SELECT PREDICTION MODEL
1002
SET ENVIRONMENTAL PARAMETERS
1003
LOAD OPTIMIZED PARAM.SET (OPT.)
1004
SELECT WATCH POINTS + RUN MODEL
1005
COVERAGE AREAS VALUES DISPLAYED
1006
MODIFY PARAMETERS FOR ENVIRONMENT OR MOD. COMPONENTS OF ANTENNA SYSTEMS OR MOD. LOCATION OF ANTENNA SYSTEMS

FIG.10

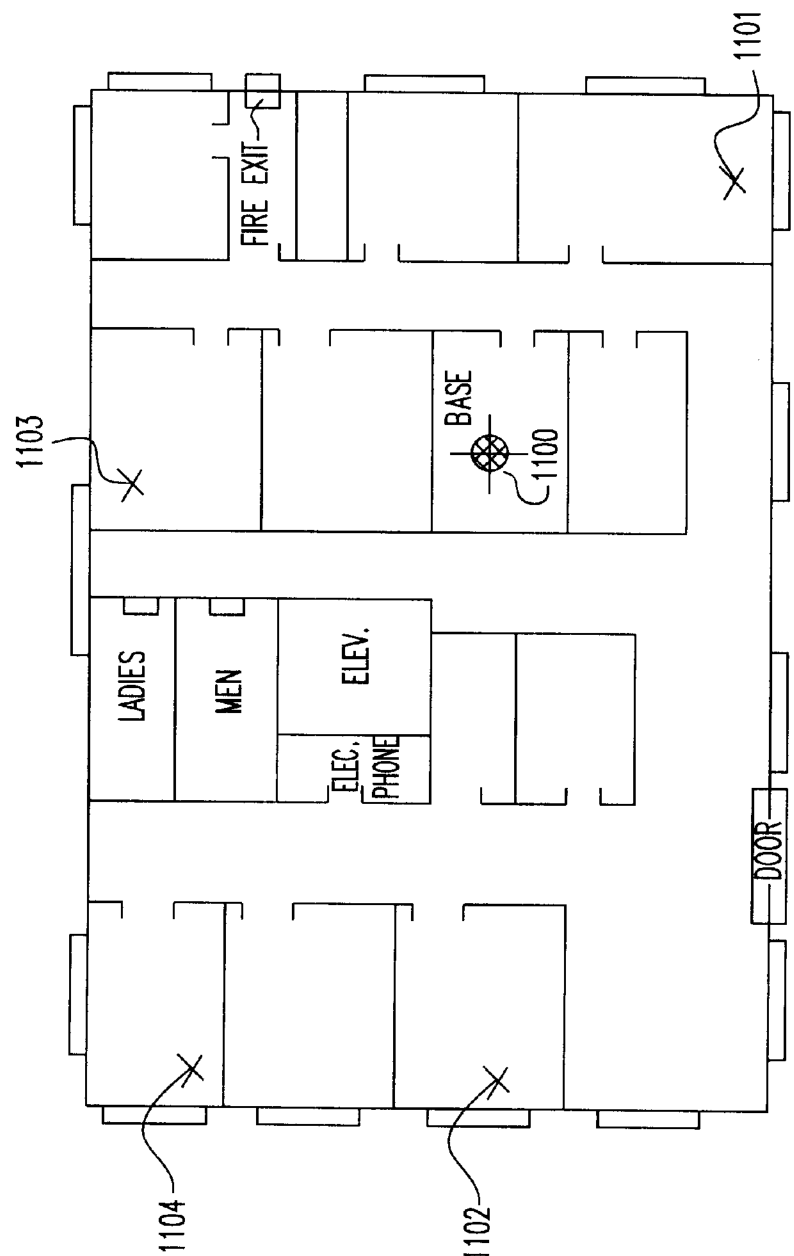

1101
FIRE EXIT
1103
BASE
1100
LADIES
MEN
ELEV.
ELEC.
PHONE
DOOR
1104
1102

FIG. 11

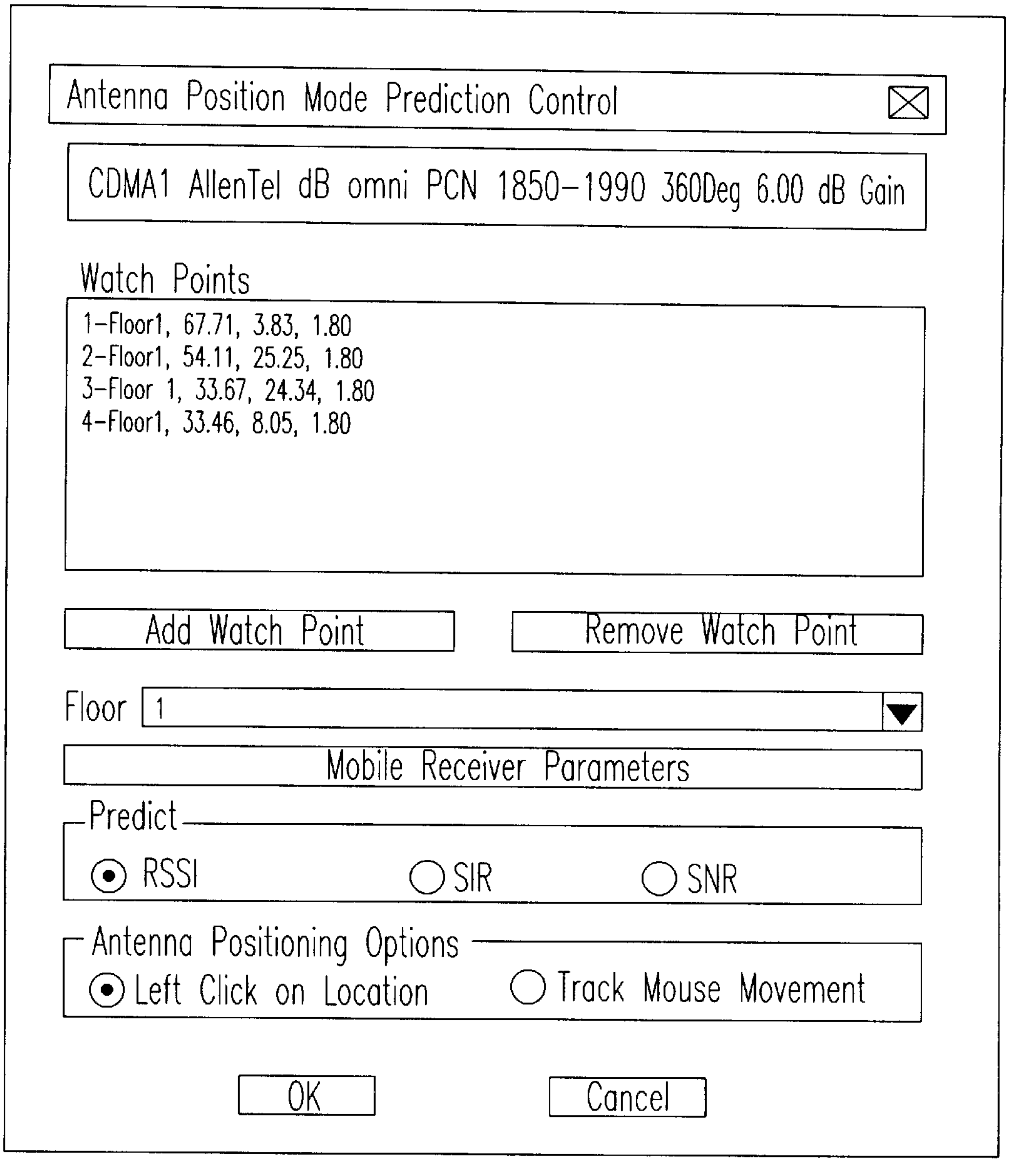

Antenna Position Mode Prediction Control
CDMA1 AllenTel dB omni PCN 1850–1990 360Deg 6.00 dB Gain
Watch Points
1–Floor1, 67.71, 3.83, 1.80
2–Floor1, 54.11, 25.25, 1.80
3–Floor 1, 33.67, 24.34, 1.80
4–Floor1, 33.46, 8.05, 1.80
Add Watch Point
Remove Watch Point
Floor
1
Mobile Receiver Parameters
Predict
RSSI
SIR
SNR
Antenna Positioning Options
Left Click on Location
Track Mouse Movement
OK
Cancel

FIG.12

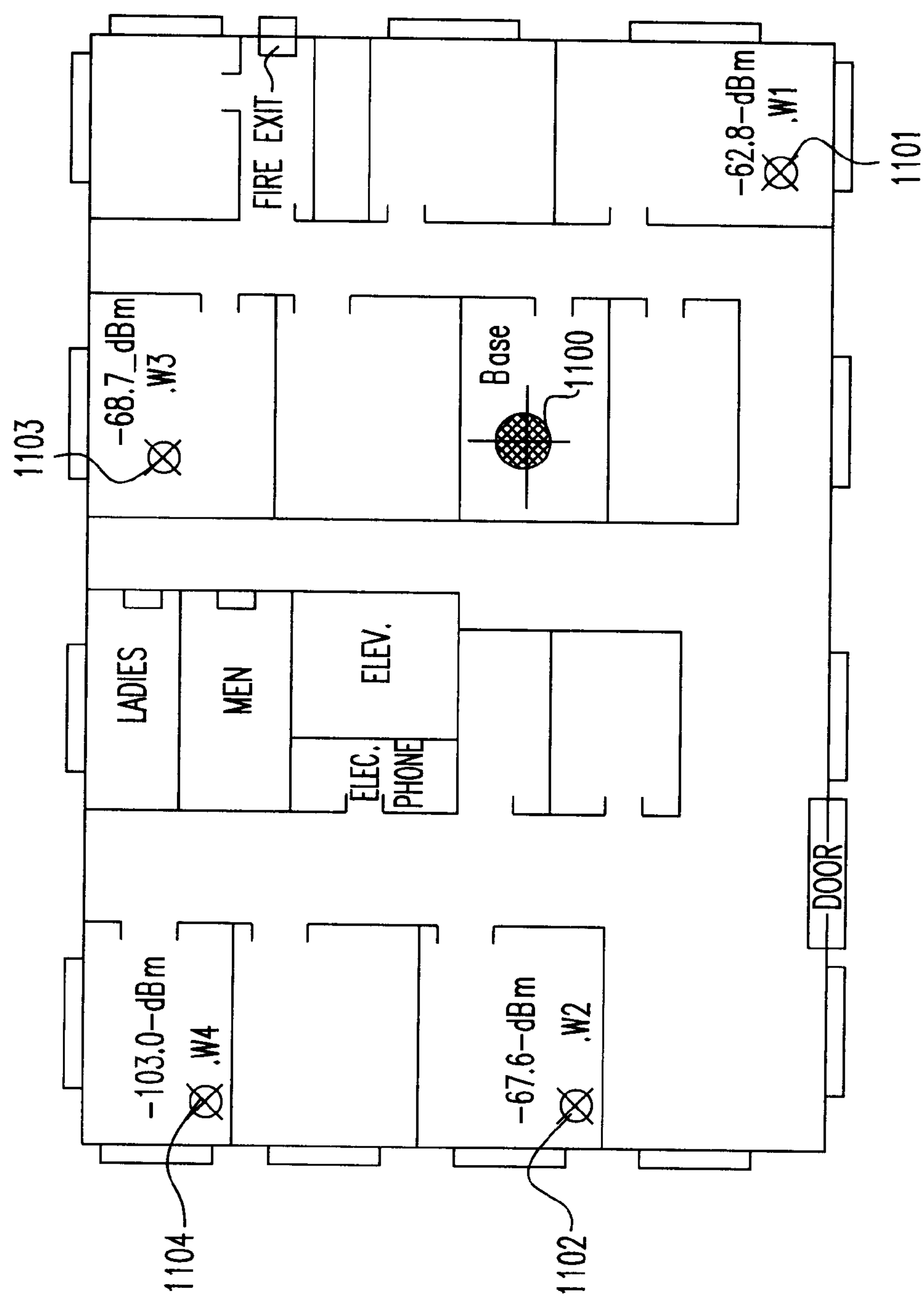

FIRE EXIT
-62.8-dBm
.W1
1101
-68.7_dBm
.W3
1103
Base
1100
LADIES
MEN
ELEV.
ELEC.
PHONE
DOOR
-103.0-dBm
.W4
1104
-67.6-dBm
.W2
1102

FIG. 13

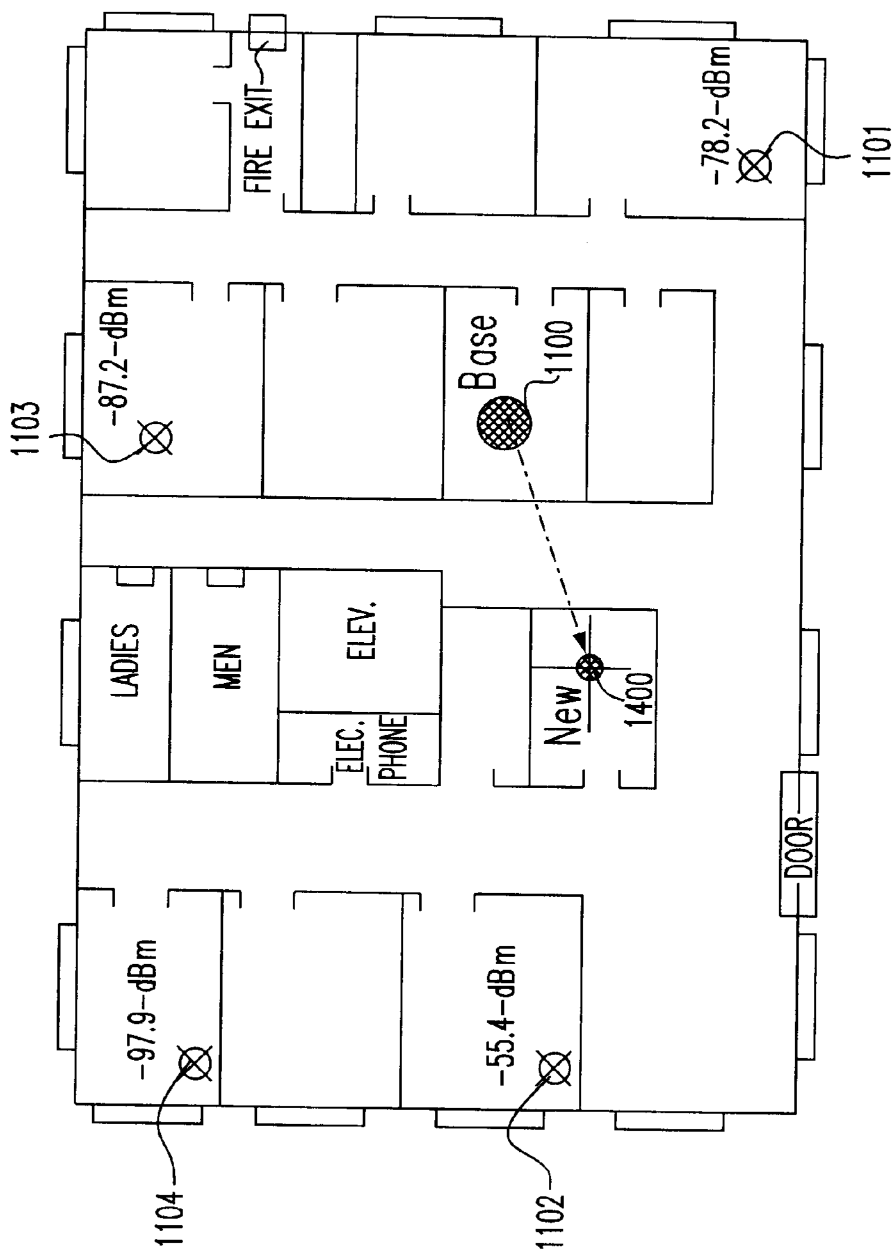

FIRE EXIT
-78.2-dBm
1101
-87.2-dBm
1103
Base
1100
LADIES
MEN
ELEV.
ELEC.
PHONE
New
1400
DOOR
-97.9-dBm
-55.4-dBm
1104
1102

FIG. 14

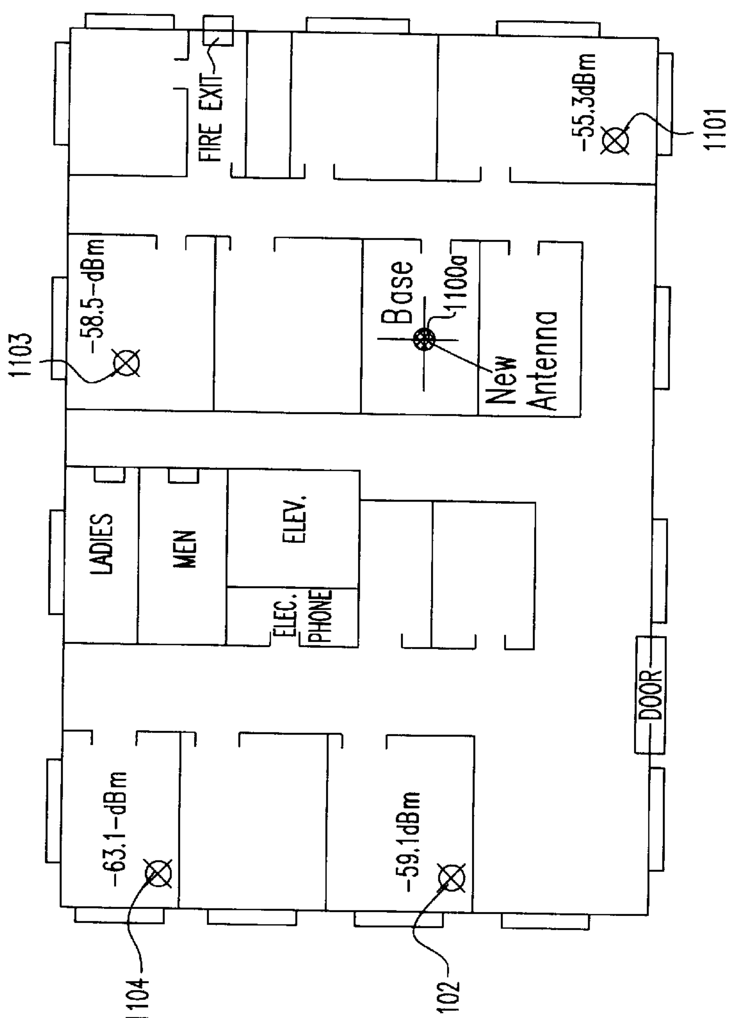

FIRE EXIT
-55.3dBm
1101
-58.5-dBm
1103
Base
1100a
New
Antenna
LADIES
MEN
ELEV.
ELEC.
PHONE
DOOR
-63.1-dBm
-59.1dBm
1104
1102

FIG. 15

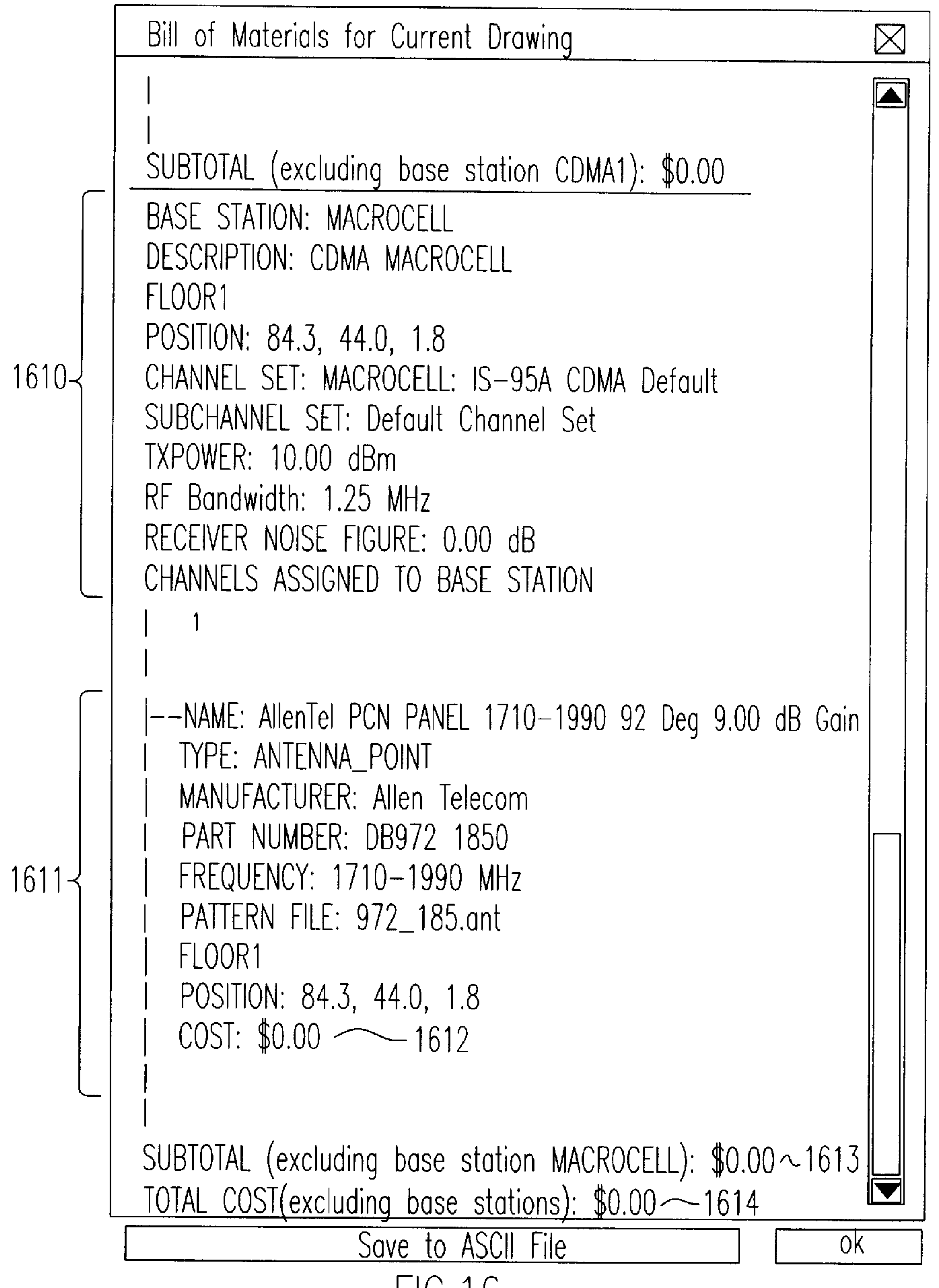

Bill of Materials for Current Drawing
SUBTOTAL (excluding base station CDMA1): $0.00
BASE STATION: MACROCELL
DESCRIPTION: CDMA MACROCELL
FLOOR1
POSITION: 84.3, 44.0, 1.8
CHANNEL SET: MACROCELL: IS-95A CDMA Default
SUBCHANNEL SET: Default Channel Set
TXPOWER: 10.00 dBm
RF Bandwidth: 1.25 MHz
RECEIVER NOISE FIGURE: 0.00 dB
CHANNELS ASSIGNED TO BASE STATION
1
1610
--NAME: AllenTel PCN PANEL 1710-1990 92 Deg 9.00 dB Gain
TYPE: ANTENNA_POINT
MANUFACTURER: Allen Telecom
PART NUMBER: DB972 1850
FREQUENCY: 1710-1990 MHz
PATTERN FILE: 972_185.ant
FLOOR1
POSITION: 84.3, 44.0, 1.8
COST: $0.00
1612
1611
SUBTOTAL (excluding base station MACROCELL): $0.00
1613
TOTAL COST(excluding base stations): $0.00
1614
Save to ASCII File
ok

FIG. 16

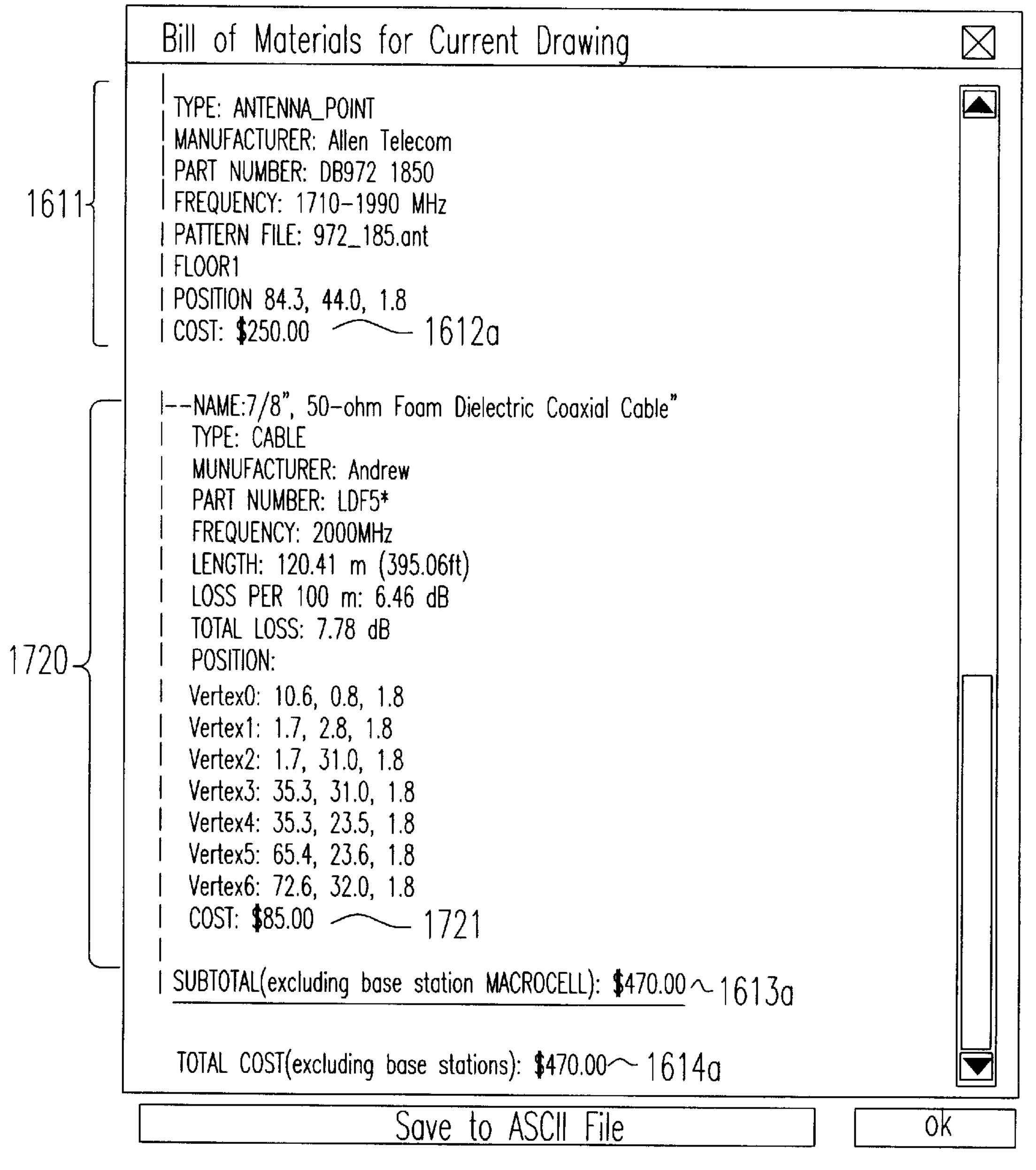

Bill of Materials for Current Drawing
TYPE: ANTENNA_POINT
MANUFACTURER: Allen Telecom
PART NUMBER: DB972 1850
FREQUENCY: 1710-1990 MHz
PATTERN FILE: 972_185.ant
FLOOR1
POSITION 84.3, 44.0, 1.8
COST: $250.00
1612a
1611
|--NAME:7/8", 50-ohm Foam Dielectric Coaxial Cable"
TYPE: CABLE
MUNUFACTURER: Andrew
PART NUMBER: LDF5*
FREQUENCY: 2000MHz
LENGTH: 120.41 m (395.06ft)
LOSS PER 100 m: 6.46 dB
TOTAL LOSS: 7.78 dB
POSITION:
Vertex0: 10.6, 0.8, 1.8
Vertex1: 1.7, 2.8, 1.8
Vertex2: 1.7, 31.0, 1.8
Vertex3: 35.3, 31.0, 1.8
Vertex4: 35.3, 23.5, 1.8
Vertex5: 65.4, 23.6, 1.8
Vertex6: 72.6, 32.0, 1.8
COST: $85.00
1721
1720
SUBTOTAL(excluding base station MACROCELL): $470.00
1613a
TOTAL COST(excluding base stations): $470.00
1614a
Save to ASCII File
ok

FIG.17

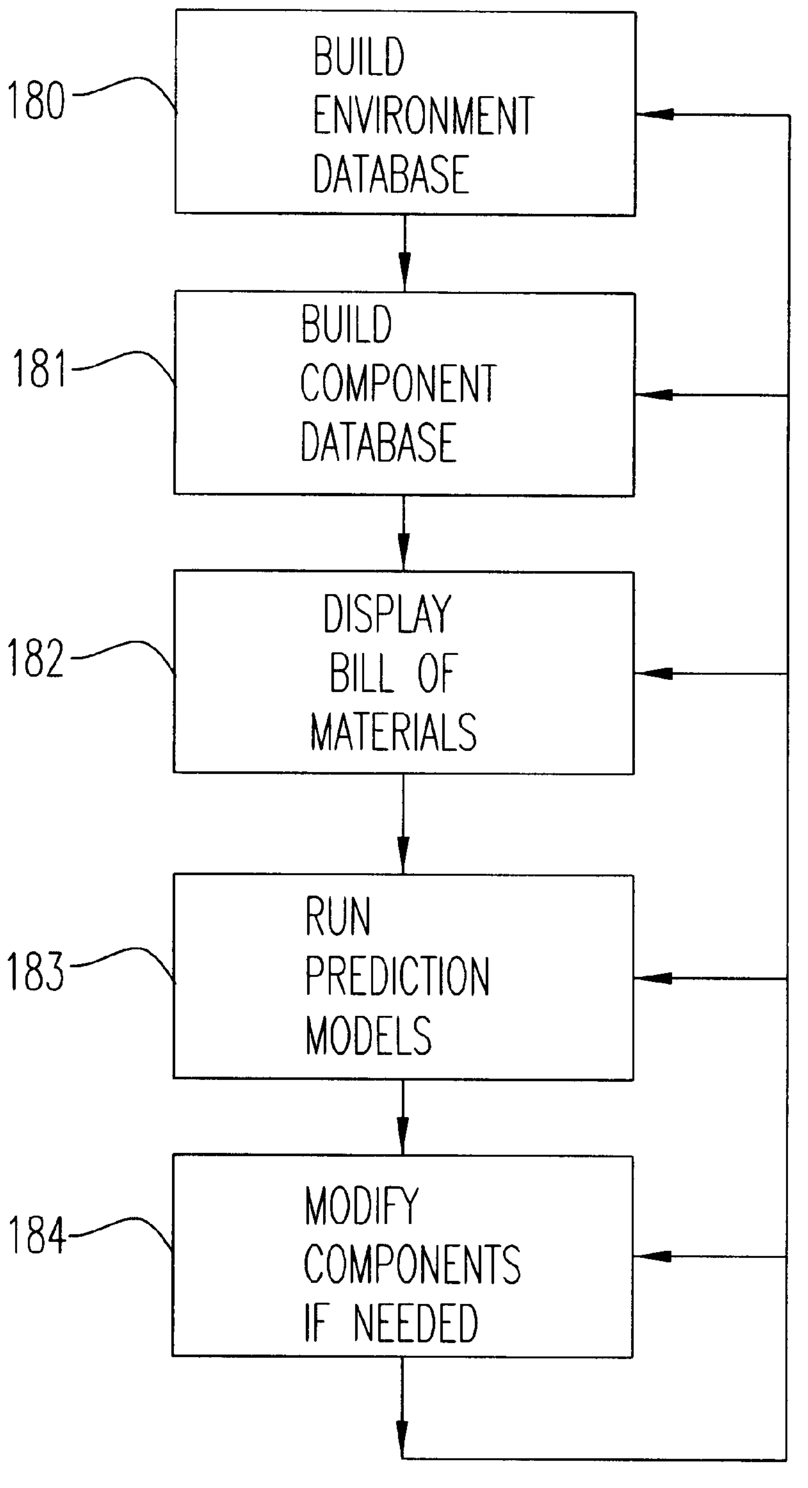
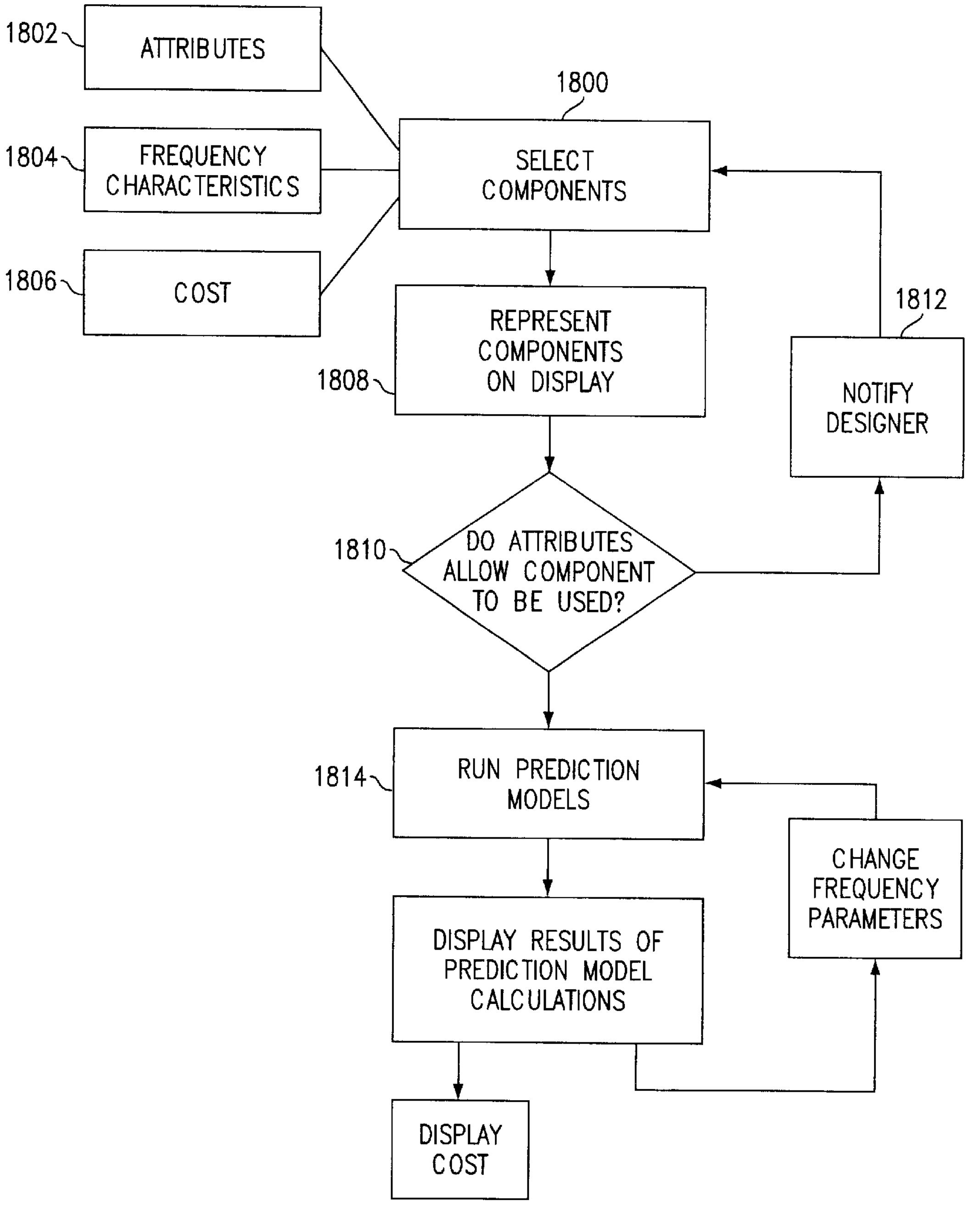

180
BUILD ENVIRONMENT DATABASE
181
BUILD COMPONENT DATABASE
182
DISPLAY BILL OF MATERIALS
183
RUN PREDICTION MODELS
184
MODIFY COMPONENTS IF NEEDED

FIG. 18



1802
ATTRIBUTES
1804
FREQUENCY CHARACTERISTICS
1806
COST
1800
SELECT COMPONENTS
REPRESENT COMPONENTS ON DISPLAY
1808
1812
NOTIFY DESIGNER
1810
DO ATTRIBUTES ALLOW COMPONENT TO BE USED?
1814
RUN PREDICTION MODELS
CHANGE FREQUENCY PARAMETERS
DISPLAY RESULTS OF PREDICTION MODEL CALCULATIONS
DISPLAY COST

FIG.19

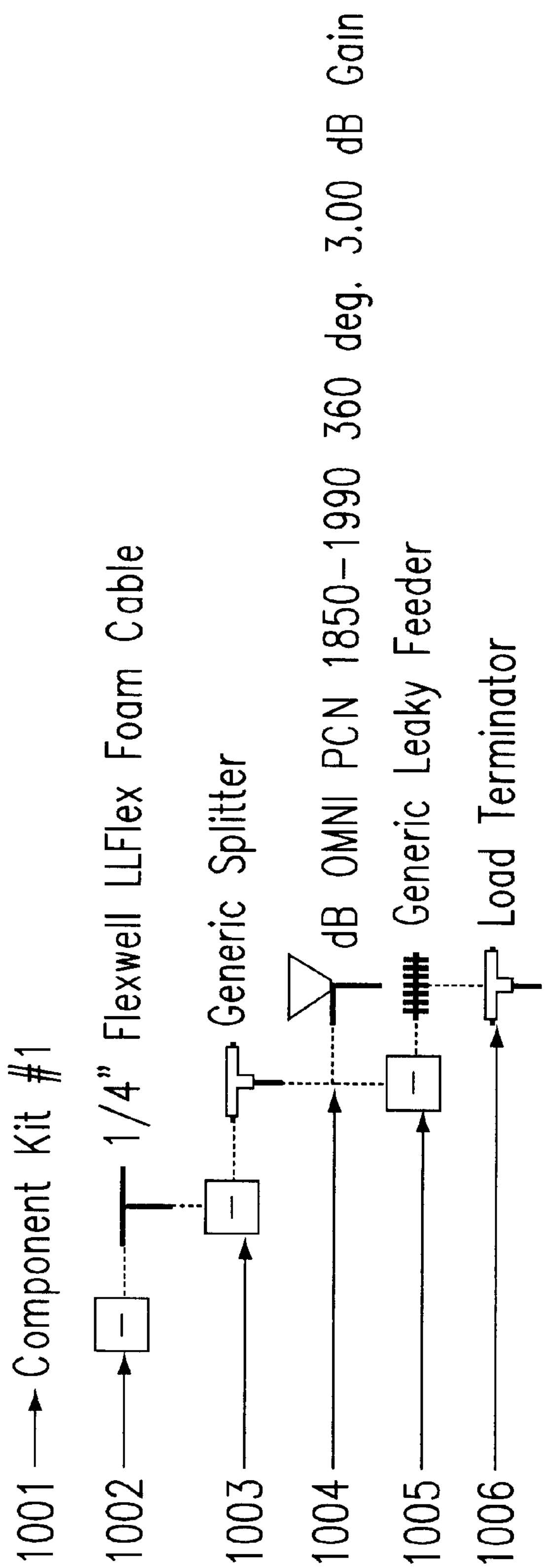

1001
Component Kit #1
1002
1/4" Flexwell LLFlex Foam Cable
1003
Generic Splitter
1004
dB OMNI PCN 1850–1990 360 deg. 3.00 dB Gain
1005
Generic Leaky Feeder
1006
Load Terminator

FIG.20

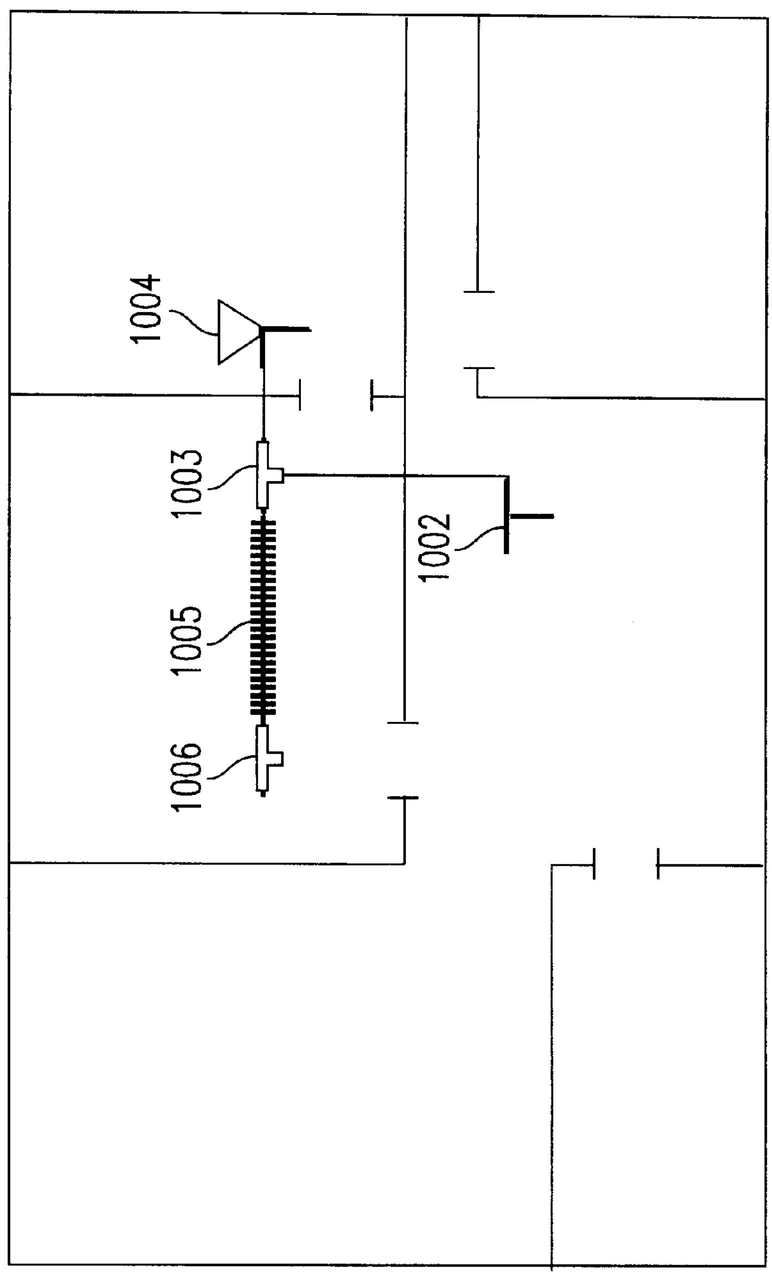


FIG.21

METHOD AND SYSTEM FOR DESIGNING OR DEPLOYING A COMMUNICATIONS NETWORK WHICH CONSIDERS FREQUENCY DEPENDENT EFFECTS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is related to the U.S. patent application Ser. Nos. 09/352,678 filed Jul. 14, 1999, now U.S. Pat. No. 6,499,006; 09/318,840 filed May 26, 1999, now U.S. Pat. No. 6,317,599; 09/318,841 filed May 26, 1999; and 09/318, 842 filed May 26, 1999, now U.S. Pat. No. 5,493,679; and is also related to the concurrently filed applications having U.S. Ser. Nos. 09/632,853, entitled "Method and System for Designing or Deploying a Communications Network which Considers Component Attributes"; and 09/633,133, entitled "Method and System for Designing or Deploying a Communications Network which Allows the Simultaneous Selection of Multiple Components", all of which are assigned to a common assignee, and the subject matter of these applications is incorporated herein by reference.

DESCRIPTION

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to engineering and management systems for the design of communications networks (both wireless and wired) and, more particularly, to a system and method for managing a real time bill of materials when designing, evaluating or optimizing the performance and/or costs of a communication system using a three-dimensional (3-D) representation of the environment. The present invention provides the design engineer with the ability to (1) group components together as a single connected or unconnected unit or "component kit" to simplify selection and assembly of hardware components, (2) have at his or her disposal in the Parts List Library performance parameters for selected components which are associated with the signal or "frequency" which will pass through the component such that electromechanical properties of the components can be considered on a frequency dependent basis automatically by the system, and (3) have at his or her disposal attributes which are associated with specific components in the Parts List Library which, acting in concert with real-time smart processing, provide the design engineer with notifications or warnings when he or she has proposed connections, components, or other arrangements which will not operate correctly in the communications network.

2. Background Description

As wireless communications use increases, radio frequency (RF) coverage within buildings and signal penetration into buildings from outside transmitting sources has quickly become an important design issue for wireless engineers who must design and deploy cellular telephone systems, paging systems, or new wireless systems and technologies such as personal communication networks or wireless local area networks. Designers are frequently requested to determine if a radio transceiver location, or base station cell site can provide reliable service throughout an entire city, an office, building, arena or campus. A common problem for wireless systems is inadequate coverage, or a "dead zone," in a specific location, such as a conference room. It is now understood that an indoor wireless PBX (private branch exchange) system or wireless local area network (WLAN) can be rendered useless by interference from nearby, similar systems. The costs of in-building and microcell devices which provide wireless coverage within a 2 kilometer radius are diminishing, and the workload for RF engineers and technicians to install these on-premises systems is increasing sharply. Rapid engineering design and deployment methods for microcell and in-building wireless systems are vital for cost-efficient build-out.

Analyzing radio signal coverage penetration and interference is of critical importance for a number of reasons. A design engineer must determine if an existing outdoor large scale wireless system, or macrocell, will provide sufficient coverage throughout a building, or group of buildings (i.e., a campus). Alternatively, wireless engineers must determine whether local area coverage will be adequately supplemented by other existing macrocells, or whether indoor wireless transceivers, or picocells, must be added. The placement of these cells is critical from both a cost and performance standpoint. If an indoor wireless system is being planned that interferes with signals from an outdoor macrocell, the design engineer must predict how much interference can be expected and where it will manifest itself within the building, or group of buildings. Also, providing a wireless system that minimizes equipment infrastructure cost as well as installation cost is of significant economic importance. As in-building and microcell wireless systems proliferate, these issues must be resolved quickly, easily, and inexpensively, in a systematic and repeatable manner.

There are many computer aided design (CAD) products on the market that can be used to design the environment used in one's place of business or campus. WiSE from Lucent Technology, Inc., SignalPro from EDX, PLAnet by Mobile Systems International, Inc., and TEMS and TEMS Light from Ericsson are examples of wireless CAD products. In practice, however, a pre-existing building or campus is designed only on paper and a database of parameters defining the environment does not readily exist. It has been difficult, if not generally impossible, to gather this disparate information and manipulate the data for the purposes of planning and implementation of indoor and outdoor RF wireless communication systems, and each new environment requires tedious manual data formatting in order to run with computer generated wireless prediction models. Recent research efforts by AT&T Laboratories, Brooklyn Polytechnic, and Virginia Tech, are described in papers and technical reports entitled "Radio Propagation Measurements and Prediction Using Three-dimensional Ray Tracing in Urban Environments at 908 MHZ and 1.9 GHz," (*IEEE Transactions on Vehicular Technology*, VOL. 48, No. 3, May 1999), by S. Kim, B. J. Guarino, Jr., T. M. Willis III, V. Erceg, S. J. Fortune, R. A. Valenzuela, L. W. Thomas, J. Ling, and J. D. Moore, (hereinafter "Radio Propagation"); "Achievable Accuracy of Site-Specific Path-Loss Predictions in Residential Environments," (*IEEE Transactions on Vehicular Technology*, VOL. 48, No. 3, May 1999), by L. Piazzi and H. L. Bertoni; "Measurements and Models for Radio Path Loss and Penetration Loss In and Around Homes and Trees at 5.85 Ghz," (*IEEE Transactions on Communications*, Vol. 46, No. 11, November 1998), by G. Durgin, T. S. Rappaport, and H. Xu; "Radio Propagation Prediction Techniques and Computer-Aided Channel Modeling for Embedded Wireless Microsystems," ARPA Annual Report, MPRG Technical Report MPRG-TR-94-12, July 1994, 14 pp., Virginia Tech, Blacksburg, by T. S. Rappaport, M. P. Koushik, J. C. Liberti, C. Pendyala, and T. P. Subramanian; "Radio Propagation Prediction Techniques and Computer-Aided Channel Modeling for Embedded Wireless

Microsystems," MPRG Technical Report MPRG-TR-95-08, July 1995, 13 pp., Virginia Tech, Blacksburg, by T. S. Rappaport, M. P. Koushik, C. Carter, and M. Ahmed; "Use of Topographic Maps with Building Information to Determine Antenna Placements and GPS Satellite Coverage for Radio Detection & Tracking in Urban Environments," MPRG Technical Report MPRG-TR-95-14, Sep. 15, 1995, 27 pp., Virginia Tech, Blacksburg, by T. S. Rappaport, M. P. Koushik, M. Ahmed, C. Carter, B. Newhall, and N. Zhang; "Use of Topographic Maps with Building Information to Determine Antenna Placement for Radio Detection and Tracking in Urban Environments," MPRG Technical Report MPRG-TR-95-19, November 1995, 184 pp., Virginia Tech, Blacksburg, by M. Ahmed, K. Blankenship, C. Carter, P. Koushik, W. Newhall, R. Skidmore, N. Zhang and T. S. Rappaport; "A Comprehensive In-Building and Microcellular Wireless Communications System Design Tool," MPRG-TR-97-13, June 1997, 122 pp., Virginia Tech, Blacksburg, by R. R. Skidmore and T. S. Rappaport; "Predicted Path Loss for Rosslyn, Va.," MPRG-TR-94-20, Dec. 9, 1994, 19 pp., Virginia Tech, Blacksburg, by S. Sandhu, P. Koushik, and T. S. Rappaport; "Predicted Path Loss for Rosslyn, Va., Second set of predictions for ORD Project on Site Specific Propagation Prediction" MPRG-TR-95-03, Mar. 5, 1995, 51 pp., Virginia Tech, Blacksburg, by S. Sandhu, P. Koushik, and T. S. Rappaport. These papers and technical reports are illustrative of the state of the art in site-specific propagation modeling and show the difficulty in obtaining databases for city environments, such as Rosslyn, Va. While the above papers describe a research comparison of measured vs. predicted signal coverage, the works do not demonstrate a systematic, repeatable and fast methodology for creating an environmental database, nor do they report a method for analyzing system performance or visualizing and placing various wireless equipment components that are required to provide signals in the deployment of a wireless system in that environment.

While there are many methods available for designing wireless networks that provide adequate coverage, there is no easy method to ensure that the system will be cost effective. For instance, even though the coverage may be more than adequate, given the chosen wireless infrastructure components, the total cost of the system could be prohibitive.

SUMMARY OF THE INVENTION

It is an object of the invention to provide a rapid and automated method for generating a bill of materials and cost information in real time, as components for a desired wireless communication system are specified and/or replaced by substitute components, while continuously predicting wireless system performance. This automatic method for comparing the cost and performance of competing products or competing design methodologies, in real time, offers a significant value for wireless engineers and provides a marked improvement over present day techniques.

It is another object of this invention to provide a communications design engineer with a software tools which allow him or her to (1) group components together as a single unit or "component kit" to simplify selection and assembly of hardware components, (2) have at his or her disposal in the Parts List Library performance parameters for selected components which are associated with the signal or "frequency" which will pass through the component such that electromechanical properties of the components can be considered on a frequency dependent basis either automatically or through the use of a prompt (i.e., these being "frequency dependent characteristics"), and (3) have at his or her disposal attributes which are associated with specific components in the Parts List Library which, acting in concert with real-time smart processing, provide the design engineer with notifications or warnings when he or she has proposed connections, components, or other arrangements which will not operate correctly in the communications network.

According to the invention, a design engineer builds a model of the desired wireless communications system and specifies each component necessary to provide sufficient or optimal system performance. A parts list is maintained, in real time, that contains a definition of each system component and its associated performance and cost parameters. Using this method, the user is able to rapidly change the physical location of components within the wireless system in order to investigate alternative designs which may use different components, such as antennas and cables; or use different RF distribution methods and/or various types of coaxial or optical splitter systems, etc. Cost parameters include both component costs and installation costs. As the system is changed through a series of "what-if" scenarios, components are replaced with substitute components, cable lengths are modified, antenna systems and base stations are re-positioned to alternate locations, etc.

Each time a component is added to or deleted from the system model, the bill of materials is automatically updated and component costs, total costs, and altered system performance specifications are immediately available to the design engineer. The designer may choose to swap components for less expensive components. The performance characteristics of the system are automatically updated as cost choices are made to enable the designer to assess the changes in performance and cost at the same time.

The communications design engineer may group several components together into a collection referred to as a "component kit". Thereafter, he or she will need only select the "component kit" for inclusion in the computerized representation of the physical environment in which the communications network will be installed. These "component kits" could be custom designed by the design engineer or, alternatively, the software package included in this system could have preselected components bundled as a "component kit". The "component kits" allow the design engineer to more simply and quickly prepare models of the communications network since he or she will be able to select essentially bundles of communications components at a time. The system; however, will be able to track all the attributes of all the components in the selected component kits, including all performance attributes, pricing information, and other physical attributes and maintenance schedules, such that calculations will automatically consider the performance criteria, pricing and compatibility for the system designed by the engineer. The component kits may be assembled in the same manner as an actual communication system, including the associated cabling and distribution system, so that connections between components are already set up when the kit is added into a system; this saves a great deal of time for the engineer.

Various attributes of components will be associated with specific components in the Parts List Library, such as, for example, whether a component is an optical component or one which requires radio signals. As another example, the length of cable in which a signal can propagate without unacceptable deterioration may be associated with the cable in the parts list library. These attributes will be considered automatically by the system of this invention such that when

a design engineer attempts to model connected components which are not properly connectable in the physical world, or when he or she attempts to use too long a cable length, etc., the system will provide a warning that the system being designed will be inoperative or be otherwise flawed. This will allow the designer to immediately recognize errors in design and correct for them during the design phase. Without such a facility, errors may not be discovered until installation or use of the system, at which point they are far more costly to repair.

Frequency dependent characteristics will also be associated with individual components in the Parts List Library. This will allow the design engineer to automatically consider the effects of signal frequency on the electrical performance of the designed communications network. This feature is especially valuable in light of the fact that most of said components are specifically designed to function in multiple frequency bands, with varying performance with respect to frequency.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, aspects and advantages will be better understood from the following detailed description of a preferred embodiment of the invention with reference to the drawings, in which:

FIG. **1** shows an example of a simplified layout of a floor plan of a building;

FIG. **2** shows effective penetration of Radio Frequency (RF) transmission into a building from a macrocell;

FIG. **3** shows a simplified layout of a floor plan of a building including an outdoor macrocell and an indoor base station;

FIG. **4** shows the layout of FIG. **3**, but with a revised base station designed to eliminate interference;

FIG. **5** is a flow diagram of a general method used to design a wireless communication network;

FIG. **6** is a flow diagram of a method used to generate estimates based on field measurements;

FIG. **7** is a flow diagram of a method used to match best propagation parameters with measured data;

FIG. **8** is a flow diagram of a method for prediction;

FIGS. **9**A and **9**B together make up a detailed flow diagram of a method to generate a design of a wireless network and determine its adequacy;

FIG. **10** is a flow diagram showing a method for using watch points during antenna repositioning or modification;

FIG. **11** shows a simplified layout of a floor plan of a building with a base station and watch points selected;

FIG. **12** shows a dialog box displaying the locations of the selected watch points and choices for display information;

FIG. **13** shows a simplified layout of a floor plan of a building with a base station and initial RSSI values for the selected watch points;

FIG. **14** shows a simplified layout of a floor plan of a building with a repositioned base station and changed RSSI values for the selected watch points;

FIG. **15** shows a simplified layout of a floor plan of a building with a re-engineered base station and changed RSSI values for the selected watch points;

FIG. **16** shows a bill of materials summary for a drawing, according the preferred embodiment of the invention;

FIG. **17** shows a bill of materials summary for a drawing after costs have been added to a database, according the preferred embodiment of the invention;

FIG. **18** is a flow diagram showing the general method of the present invention;

FIG. **19** is a flow diagram showing the mechanisms for considering the effects of various attributes on and frequency characteristics on the communications system design, and, as required for notifying the designer of any inherent design flaws;

FIG. **20** is a computer display showing the assembly of a "component kit" according to the present invention; and

FIG. **21** is a schematic representation of a floor plan on which the components of a "component kit" have been displayed.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT OF THE INVENTION

Design of Wireless Communication Systems

Using the present method, it is now possible to assess the RF environment in a systematic, organized fashion by quickly viewing signal strength, or interference levels, or other wireless system performance measures. The current embodiment is designed specifically for use with the SitePlanner™ suite of products available from Wireless Valley Communications, Inc. of Blacksburg, Va. However, it will be apparent to one skilled in the art that the method could be practiced with other products either now known or to be developed in the future. (SitePlanner is a trademark of Wireless Valley Communications, Inc.)

Referring now to FIG. **1**, there is shown a two-dimensional (2-D) simplified example of a layout of a building floor plan. The method uses 3-D computer aided design (CAD) renditions of a building, or a collection of buildings and/or surrounding terrain and foliage. However, for simplicity of illustration a 2-D figure is used. The various physical objects within the environment such as external walls **101** internal walls **102** and floors **103** are assigned appropriate physical, electrical, and aesthetic values. For example, outside walls **101** may be given a 10 dB attenuation loss, signals passing through interior walls **102** may be assigned 3 dB attenuation loss, and windows **104** may show a 2 dB RF penetration loss. In addition to attenuation, the obstructions **101**, **102** and **103** are assigned other properties including reflectivity and surface roughness.

Estimated partition electrical properties loss values can be extracted from extensive propagation measurements already published, which are deduced from field experience, or the partition losses of a particular object can be measured directly and optimized instantly using the present invention combined with those methods described in the copending application Ser. No. 09/221,985, entitled "System for Creating a Computer Model and Measurement Database of a Wireless Communication Network" filed by T. S. Rappaport and R. R. Skidmore. Once the appropriate physical and electrical parameters are specified, any desired number of hardware components of RF sources can be placed in the 3-D building database, and received signal strengths (RSSI), network throughput, bit or frame or packet error rate, network delay, or carrier-to-interference (C/I), carrier-to-noise (C/N), or chip energy to interference (Ec/Io) ratios can be plotted directly onto the CAD drawing. The 3-D environment database could be built by a number of methods, the preferred method being disclosed in the concurrently filed, copending application Ser. No. 09/318,841. Traffic capacity analysis, frequency planning, co-channel interference analysis can be performed in the invention along with RF coverage. Other system performance metrics may be easily incorporated by one skilled in the art through well known equations.

FIG. 2 depicts effective RF penetration into the building from the distant macrocell using a close-in virtual macrocell transmitting into the lossless distributed antenna.

Referring to FIG. 2, there are several windows **104**, and even a large glass foyer **105**, on the north wall of the building, so RF penetration into this part of the building is quite good, as shown by contour lines **108** and **109** for 0 dB and −30 dB, respectively. Even so, interior walls **102** cause signal levels in some areas to drop below a minimum useable signal strength of about −90 dBm, especially in some of the southern rooms, as shown by contour line **110**. Consequently, macrocell coverage there will probably be poor.

Other outdoor macrocells can be modeled in the same way, and their signal strength contours plotted, to determine if hand-offs can compensate for the inadequacies of the macrocell north of the building. If not, then indoor picocells (and their distributed feed systems, antennas, and antenna patterns) can be easily added if necessary, and their performance checked using the method, to complement coverage provided by the macrocells.

The mathematical propagation models used to predict and optimize antenna positioning in a desired environment may include a number of predictive techniques models, such as those described in the previously cited and following technical reports and papers: "Interactive Coverage Region and System Design Simulation for Wireless Communication Systems in Multi-floored Indoor Environments, SMT Plus," *IEEE ICUPC '96 Proceedings*, by R. R. Skidmore, T. S. Rappaport, and L. Abbott which is hereby incorporated by reference. Some simple models are also briefly described in "SitePlanner 3.16 for Windows 95/98/NT User's Manual" (Wireless Valley Communications, Inc. 1999), hereby incorporated by reference. It would be apparent to one skilled in the art how to apply other system performance models to this method.

Interference, instead of radio signal strength, is the dominant performance-limiting factor in many situations due to increased wireless communications use. Modeling interference from any source to an established or contemplated wireless system is straightforward using the method. Suppose, for example, that an indoor wireless communication system is assigned a frequency set identical to that of an outdoor wireless system. Although the indoor system may provide sufficient RSSI throughout its coverage area, interference from the outside system may still render the indoor wireless system ineffectual in certain parts of the building.

Caution must be used, however, when modeling and analyzing interference, since the detrimental effect may also depend upon technologies and/or signal processing technologies, not just signal power levels. For example, a geographic area could have similar narrowband and/or wideband in the 800 MHZ cellular bands, for instance with Advanced Mobile Phone System (AMPS) and Code Division Multiple Access (CDMA) systems, but users using either technology may be able to coexist if their respective demodulation processes reject interference provided by the undesired system. The current embodiment of this invention allows the user to select the air interface/technology being used by the wireless system being designed and automatically adjusts the prediction of interference accordingly.

FIG. 3 shows another rendition of the office building example, but an indoor wireless system **107** has been added. In this example, 800 MHZ AMPS technology is assigned to both transmitters **106** and **107**. Differing wireless standards and technologies such as CDMA and Global System Mobile (GSM) could have been selected as well. The present invention uses a database to represent the exact physical air interface standards of a wide range of technologies and may be easily edited for future interface standards. As new technologies are developed, one skilled in the art could easily modify this invention to include the new technologies.

The outdoor wireless system **106** is now interfering with the indoor network, and the effect is checked by plotting C/I contours **111** and **112** at 0 dB and −30 dB, respectively, for the outdoor system and also plotting C/I contours **113** and **114** at 0 dB and −30 dB for the indoor system. The 0 dB contour **114** shows where the desired and interfering signal levels are equal, so the interfering outdoor system's signal predominates in areas outside this contour. It is obvious that the indoor network is rendered useless throughout many parts of the building. There are a number of possible solutions that may be analyzed by a designer using the present invention.

One solution is to change the indoor system's antenna location or increase the transmitted power, add more nodes, or select a different frequency set. These changes may be made with the simple click of a mouse in the method of the invention, so that new channel sets, antenna locations, or alternative antenna systems (such as in-building distributed systems, directional antennas, or leaky feeders) may be evaluated quickly, thereby eliminating guesswork and/or costly on-site experimentation with actual hardware. Instead of displaying contours of coverage or interference, the present invention also allows the user to specify fixed or moveable watch points that indicate or display predicted performance in extremely rapid fashion at specific points in the environment.

For example, FIG. 4 illustrates how the same indoor wireless system of FIG. 3 can provide adequate C/I protection when connected to a distributed indoor antenna system consisting of a two-way splitter **401** (3 dB loss+insertion loss) and two 40 foot cable runs **402** to popular commercial indoor omnidirectional antennas **403**. A look at the new 0 dB contour lines **111** and **215**, and −30 dB contour lines **112***a* and **216** show that the coverage inside the building is now adequate; the outdoor system **106** no longer causes significant interference in most parts of the building. Watch points allow a user to instantly determine spot coverage or other system performance without having to wait for the computation and display of contour plots.

The method allows any type of distributed antenna system to be modeled within seconds, while continuously monitoring and analyzing the component and installation cost and resulting link budget, as disclosed below, enabling "what-if" designs to be carried out on the fly with minimum guess work and wasted time. It is clear that while an RF system is shown and described herein, the same concepts may be applied to any communications network, with a wide range of distribution methods and components.

In the present embodiment of the invention, the designer identifies locations in the 3-D environmental database where certain levels of wireless system performance are desirable or critical. These locations, termed "watch points", are points in three-dimensional space which the designer identifies by visually pointing and/or clicking with a mouse or other input device at the desired location in the 3-D environmental database. Any number of such watch points may be placed throughout the 3-D environment at any location. Watch points may be designated prior to performing a performance prediction on a given wireless communication system, or may be dynamically created by the user at any

time during the course of a wireless system performance calculation using the same point and click technique described above.

Watch points provide graphical and/or textual feedback to a designer regarding the wireless system performance throughout the environment. Depending on the type of visual feedback desired by the designer, watch points may take the form of one or more of the following:

A computed number displayed as text that represents received signal strength (RSSI), signal-to-interference ratio (SIR), signal-to-noise ratio (SNR), frame error rate (FER), bit error rate (BER), or other wireless system performance metrics;

A small region of solid color whose shade and/or tint varies relative to some computed wireless system performance metric;

Colored lines linking the watch point location with the location one or more antennas in the wireless communication system, where the color, thickness, and/or other physical aspect of the connecting line varies relative to some computed wireless system performance metric and dependent upon whether the forward or reverse wireless system channel is being analyzed;

Other form designated by the designer; or

Any combination of the above.

In all cases, the graphical and/or textual representation of each watch point is updated in real-time as a result of the instantaneous computation of the wireless system performance metrics, which are linked to the 3-D environmental database, and initiated due to dynamic changes being made to the wireless system configuration and/or watch point position itself by the user. For example, if the user repositions an antenna using the mouse or other input device, the effect of doing so on the overall wireless system performance is computed and the results are displayed via changes in the appearance of watch points. In addition, numerical values predicted at the watch points are displayed in summary in a dialog window and written to a text file for later analysis. This process is described in greater detail in the following sections.

The preferred embodiment of the invention utilizes a 3-D environmental database containing information relevant to the prediction of wireless communication system performance. This information includes but is not limited to the location, and the physical and electromagnetic properties of obstructions within the 3-D environment, where an obstruction could be any physical object or landscape feature within the environment (e.g., walls, doors, windows, buildings, trees, terrain features, etc.), as well as the position and physical and electrical properties of communications hardware to be used or simulated in the environment.

The designer identifies the location and type of all wireless communication system equipment within the 3-D environmental database. This point-and-click process involves the designer selecting the desired component from a computer parts database and then visually positioning, orienting, and interconnecting various hardware components within the 3-D environmental database to form complete wireless communication systems. The preferred embodiment of the computer parts database is more fully described below. The resulting interconnected network of RF hardware components (commonly known as a wireless distributed antenna) is preferably assembled using either a drag and drop technique or a pick and place and is graphically displayed overlaid upon the 3-D environmental database, and utilizes electromechanical information available for each component via the parts list library in order to fully describe the physical operating characteristics of the wireless communication system (e.g., the system noise figure, antenna radiation characteristics, frequencies, etc.). This information is directly utilized during the prediction of wireless system performance metrics and is discussed later.

The present invention represents a dramatic improvement over prior art by providing the design engineer with instant feedback on wireless system performance metrics as the user alters the physical location of switches, routers, repeaters, transducers, couplers, transmitters, receivers, and other components described elsewhere or which would be known by those of skill in the art, or otherwise modifies the antenna system. The current embodiment utilizes the concept of watch points to implement this. Multiple methods of display and a wide range of settings are available for the designer to use in optimizing antenna placement based upon wireless system performance values displayed at each watch point. One skilled in the art could see how watch points as they are herein described could apply to different implementations as well. Descriptions of the different techniques implemented in the current invention are provided in the following sections.

One form of the method allows the designer to dynamically alter the position, orientation, and/or type of any hardware component utilized within a wireless communication system modeled in a 3-D environmental database. Using this technique, the designer may identify watch points representing critical areas of the 3-D environment that require a certain level of wireless system performance. Such areas could include the office of the Chief Executive Officer (CEO) of a company, a conference room, a city park, or the office of a surgeon on call. Next the designer selects the component of interest within the wireless system. In the present invention, this would be the selection of an antenna or leaky feeder antenna, for example, but one skilled in the art could see that this could be any physical antenna system component. Once the desired hardware component is selected, the designer may begin making changes to the state of the component. For example, by moving the mouse or other input device cursor, the user could effectively relocate the selected component to another position in the 3-D environmental database. This involves the user visually moving the mouse cursor, in real-time, such that the cursor resides in another portions of the 3-D database. The present invention recalculates wireless system performance based upon RSSI, SIR, SNR, FER, BER, or other metric, incorporating the user's desired change in the position of the selected component.

The calculations combine the electromechanical properties of each component in the wireless communication system (e.g., noise figure, attenuation loss or amplification, antenna radiation pattern, etc.), the electromagnetic properties of the 3-D environmental database, and radio wave propagation techniques (detailed later) to provide an estimate of the wireless system performance. Calculations are performed at each watch point the user has identified, and the graphical display of the watch point is updated to reflect the result of the calculations.

As the user moves the mouse cursor and effectively repositions the selected component, the overall performance of the wireless communication system may be altered. For example, if the selected component is an antenna, repositioning the antenna changes the origination point of radio wave signals being broadcast from the antenna, and can thus dramatically change the reception of adequate RF signal throughout the environment. Because the graphical display

of the watch points is updated in real-time as the selected component is repositioned, the designer is provided instant feedback on the revised wireless system performance, and can make design decisions based upon the viability of multiple proposed locations and/or wireless system configurations rapidly. While many of the concepts discussed above deal with wireless networks, one of ordinary skill in the art would understand that similar features may be implemented for optical, infrared, or baseband networks that use fixed or portable terminals.

In addition to the functionality described above, the designer is free to add additional watch points in any location within the 3-D environmental database at any time during a communication system performance prediction. In the current implementation, the designer clicks with the mouse or other input device on the desired location in the 3-D environmental database to create a new watch point at the selected location that is then updated throughout the remainder of the performance prediction.

In a similar fashion, the preferred embodiment enables a designer to reorient a selected antenna in real-time with respect to any coordinate axis while the graphical display of all drawing watch points is updated to reflect the revised wireless system performance metrics as a result of the new antenna orientation.

In a similar fashion, a designer may replace an existing hardware component in the wireless communication system with any component available from the parts list library. In doing so, the changes to the wireless communication system performance as a result of the replacement is reflected in the graphical display of the watch points.

In a similar fashion, a designer may selectively include or exclude any subset of components within the wireless communication system while selecting components to involve in the wireless system performance calculation. For example, a designer could consider the effect of repositioning a single antenna, or could consider the combined, composite effect on the watch points as individual antennas are repositioned within a wireless system network consisting of additional, fixed antenna placements.

In a similar fashion, the designer may choose to allow watch points to be mobile. That is, instead of positioning a watch point and having the graphical display of the watch point reflect the changing wireless system performance metric, the designer could instead identify a watch point whose position is mobile but whose graphical display remains constant. In this scenario, the position of the watch point fluctuates along a linear path traced between itself and the current location of the mouse cursor until a position within the 3-D database is found at which the desired level of wireless system performance metric is maintained. For example, the designer may create a watch point to maintain a constant graphical display synonymous with −65 dBm RSSI. As the user repositions, reorients, or otherwise alters components within the wireless communication system, the watch point alters its position within the 3-D environmental database until a position is found at which a calculated value of −65 dBm RSSI is determined.

In addition to enabling a designer to reposition, reorient, and/or replace wireless system components in real-time while visualizing the impact of such changes at selected watch points within the 3-D database, the user may choose to maintain the current configuration of the wireless communication system and instead create a single, mobile watch point. The watch point thus created is dynamically repositioned within the 3-D environmental database in real-time by the user by simply repositioning the mouse cursor. Positioning the mouse cursor at a given location within the 3-D environmental database is equivalent to repositioning the watch point to match that location. In the present invention, this technique is used to allow the mobile watch point to represent a mobile user in the 3-D environmental database. As in the previous scenarios, the graphical display of the watch point is updated in real-time to reflect predicted wireless system performance metrics at the watch point position. The designer is free to select individual subsets of wireless system components to involve in the calculations of wireless system performance. Thus the graphical display of the watch point may reflect the performance metrics specific to individual wireless system components or the composite performance metrics due to the combined effect of multiple selected components. For example, the radiating power of multiple antennas can be combined into a single measure of received signal strength.

The two primary uses of the single mobile watch point technique involve the analysis of the forward link (or down link) and reverse link (or up link) of the wireless system. The forward link of a wireless communication system involves the flow of radio signals from the fixed wireless system to the mobile user, while the reverse link of a wireless communication system involves the flow of radio signals from the mobile user to the fixed wireless system. In the present embodiment, line segments are drawn between the mobile watch point (which is also the mouse cursor) to each antenna the designer has included in the wireless system performance prediction. In addition, the individual or subsets of antennas identified as having the best wireless system performance characteristics are differentiated from the other antennas by altering the color and/or other physical appearance of the connector lines between the antennas and the watch point. As the designer then repositions the mouse cursor, the selected location for the watch point in the 3-D database, and therefore the effective location of the mobile user, is adjusted to match that of the mouse cursor. The wireless system performance metrics are recalculated at the watch point location for the antenna components selected by the designer, and the graphical display of the watch point and all connector lines is updated accordingly.

Another improvement over the prior art is the ability to dynamically model the repositioning of leaky feeder antennas and visualize the effects on wireless system performance. A leaky feeder antenna can be thought of as a cable with many holes regularly spaced along its length. Such a cable would experience a signal loss or emanation at every hole and would thus radiate RF energy along the entire cable length. Leaky feeder antenna, or lossy coaxial cable as it is sometimes referred, can be thought of as analogous to a soaker hose where water flows in at the head of the hose and leaks out through a series of holes. The present method allows the designer to dynamically re-position a portion of the leaky feeder antenna and see in real time the effects on wireless system performance at the specified watch points. In the preferred embodiment, distributed antenna systems can be analyzed in terms of the contributions of individual antennas or collections of antennas taken as a whole, providing "composite" results in the latter case.

Referring to FIG. **5**, there is shown the general method of the invention. Before one can run an automated predictive model on a desired environment, a 3-D electronic representation of that environment must be created in function block **10**. The preferred method for generating a 3-D building or environment database is disclosed in the concurrently filed, copending application Ser. No. 09/318,841. The resulting definition utilizes a specially formatted vector database

format and comprises lines and polygons rather than individual pixels (as in a raster format). The arrangement of lines and polygons in the database corresponds to obstructions/partitions in the environment. For example, a line in a database could represent a wall, a door, tree, a building wall, or some other obstruction/partition in the modeled environment.

From the standpoint of radio wave propagation, each of the obstruction/partition in an environment has several electromagnetic properties. When a radio wave signal intersects a physical surface, several things occur. A certain percentage of the radio wave reflects off of the surface and continues along an altered trajectory. A certain percentage of the radio wave penetrates through or is absorbed by the surface and continues along its course. A certain percentage of the radio wave is scattered upon striking the surface. The electromagnetic properties given to the obstruction/partitions define this interaction. Each obstruction/partitions has parameters that include an attenuation factor, surface roughness, and reflectivity. The attenuation factor determines the amount of power a radio signal loses upon striking a given obstruction. The reflectivity determines the amount of the radio signal that is reflected from the obstruction. The surface roughness provides information used to determine how much of the radio signal is scattered and/or dissipated upon striking an obstruction of the given type.

Once this 3-D database of obstruction data has been built, the design engineer performs computer aided design and experimentation of a wireless network to be deployed in the modeled environment in function block **11**, to be described later. Cost and wireless system performance target parameters, transmitters, channel lists, placement options and antenna systems are all taken into account by the present invention.

In order to fine tune the experimental predictions, RF measurements may be optionally taken in function block **12**. A preferred method for collecting RF measurements is disclosed in copending application Ser. No. 09/221,985, supra. If necessary, database parameters that define the partition/obstruction characteristics may be modified using RF measurements as a guide to more accurately represent the modeled 3-D environment in function block **13**.

The results of the predictive models may be displayed in 3-D overlaid with the RF measurement data, if any, at any time in function block **14**. The design engineer analyzes the differences in the predicted and actual measurements in function block **15**, and then modifies the RF predictive models, if needed, in function block **16**. If necessary, the 3-D environment database may be modified based on the actual measurements to more accurately represent the wireless system coverage areas in function block **10**, and so on iteratively until done. The designer can optionally continue with any other step in this process, as desired.

The method of invention may be used in a variety of ways depending on the goals of the design engineer. FIG. **6** shows a variant on the above method used to generate estimates based on RF measurements. A 3-D database of the environment must still be generated in function block **10**. Field measurements are collected in function block **12**. The RF measurement data are then incorporated into the drawing of the environment in function block **61**. The design engineer may then generate estimates of power level and location of potential transmitters in function block **62**.

FIG. **7** shows a variant of the method used to achieve optimal prediction accuracy using RF measured data. Once again, a 3-D database of the environment is generated in function block **10**. However, before collecting field measurements, the design engineer creates a channel plan with "virtual" macrocell locations and power levels in function block **71**. The field measurements are then collected in function block **12** and the "virtual" locations of interfering transmitters can be determined in function block **72**. The best propagation parameters are then matched with measured data from the interferers in function block **73**.

A more detailed description of the method for prediction used in the present invention is now described. Referring to FIG. **8**, the 3-D environment definition is input in function block **801**. The first step required before predicting the performance of the wireless communication system is to model the wireless system with the 3-D environment. Antennas and types of related components and locations are selected in function block **802**. The desired antennas are chosen from a parts list of wireless hardware devices that may include a variety of commercially available devices. Each antenna is placed at a desired location within the environment, for instance, in a specific room on a floor of a building or on a flag pole in front of a building. A number of other components may be created and placed either within or connected to each antenna system. These components include, but are not limited to: cables, leaky feeder antennas, splitters, connectors, amplifiers, or any other user defined component.

FIGS. **9A** and **9B** show a method for adding antenna systems to a desired environment and generally for running trade-off analyses. First, the designer positions and defines outdoor wireless communication systems, if necessary in function block **901**. Next, the designer positions and defines indoor base stations in function block **902**. The methods of function blocks **901** and **902** differ in that the components of indoor wireless system will typically be different than an outdoor wireless system. In both cases, the designer is guided through a series of pull down menus and point-and-click options to define the location, type of hardware components and associated performance characteristics of the antenna systems. This data is stored in a database, that also contains cost and manufacturing specific information to produce a complete Bill of Materials list automatically, to be viewed at any time.

In order to fully describe a communication system in a newly created (or to be modified) wireless or wired system, the designer specifies the air interface/technology and frequencies associated with network protocol, physical media, or a network such as a wireless system in function block **903**. For a wireless system, the designer then lays out the full antenna system for the wireless network in function block **904**. Components such as base stations, cabling, connectors, amplifiers and other items of the antenna system are then selected from a parts list library containing information on commercially available hardware components in function block **905**. Next, the air interface and technology specific parameters are assigned and channel frequencies are customized for the wireless system in function block **906**. The channel frequencies are selected from pre-assigned channel clusters and assigned to the wireless system in function block **907**. An antenna system is then configured in function block **908**, selecting antennas from the parts list library as described above. The antennas are placed on the floor plan in function block **909** using a point and click of a mouse or other positioning device to visually place each component in the 3-D database.

At this or any time after a component has been placed on a floor, the designer may view a bill of materials in function block **910**. If necessary, the parts list may be modified to add or delete components or modify a component's cost or

performance characteristics in function block **911**. Components may be replaced or swapped for similar components for a quick trade-off analysis of both wireless system performance and overall cost in function block **912**. Components may be added, deleted or modified to more fully define the wireless communications system in function block **913**. The designer may redisplay the view of the environment including the wireless communication system, RF measurement data, and/or wireless system predicted performance results in a variety of forms, including 2-D, 3-D wireframe, 3-D wireframe with hidden lines, 3-D shaded, 3-D rendered or 3-D photorealistic rendering, at any time in function block **914**.

Typically, a designer will add network system components in succession, where each newly placed system component connects to a previously positioned component in the network. For a wireless network, one should note that cables and leaky feeder antennas are defined by a series of vertices connected by lines representing lengths of cabling as they are placed on a floor. This is also done for fiber optic and baseband cables. Cables and leaky feeders may also stretch vertically across building floors, down the sides of buildings, through elevator shafts, etc., simply by adding a vertex in the cable, changing the vertical height, and then continuing to place cable in new locations, in function block **915**. The designer does not need to manipulate a 3-D view of the environment and attempt to guide the cables vertically in the 3-D model. The designer may repeat any of the steps in this process, in any order, in the present invention.

Referring again to FIG. **8**, once the 3-D environment has been defined and antennas, cables and other objects which are used in network design have been selected and located, the wireless system performance prediction models may be run in function block **803**. A variety of different such models are available and may be used in succession, or alone to generate a sufficient number of "what-if" scenarios for predicting and optimizing of antenna placements and component selections.

Referring to FIG. **10**, a method for predictive modeling according the invention is shown. First, the designer selects the desired wireless system performance prediction model in function block **1001**. Preferred models are:

- Wall/floor Attenuation Factor, Multiple Path Loss Exponent Model,
- Wall/floor Attenuation Factor, Single Path Loss Exponent Model,
- True Point-to-Point Multiple Path Loss Exponent Model,
- True Point-to-Point Single Path Loss Exponent Model,
- Distance Dependent Multiple Breakpoint Model,
- Distance Dependent Multiple Path Loss Exponent Model,
- Distance Dependent Single Path Loss Exponent Model, or other models as desired by the design engineer.

Also, models for propagation of optical and baseband signals, such as loss, coupling loss, distance-dependent loss, and gains are contemplated.

The physical and electrical properties of obstructions in the 3-D environment are set in function block **1002**. Although not all parameters are used for every possible predictive model, one skilled in the art would understand which parameters are necessary for a selected model. Parameters that may be entered include:

- Prediction configuration—RSSI, C/I, and/or C/N (carrier to noise ratio);
- Mobile Receiver (RX) Parameters—power, antenna gain, body loss, portable RX noise figure, portable RX height above floor;
- Propagation parameters
  - Partition Attenuation Factors
  - Floor Attenuation Factors
  - Path Loss Exponents
  - Multiple Breakpoints
  - Reflectivity
  - Surface Roughness
  - Antenna Polarization
- other parameters as necessary for a given model The designer may save sets of physical, electrical and aesthetic parameters for later re-use. If such a parameter set has been previously saved, the designer may load that set in function block **1003**, thereby overwriting any parameters already in selected.

A designer then may select a number of watch points in function block **1004** to monitor for wireless system performance. Referring now to FIG. **11**, there is shown a simplified layout of a floor plan with a base station **1100**. The designer may use a mouse or other positioning device to point and click to any number of locations in the floor plan to select critical areas, or watch points, for monitoring. Here, for instance, four watch points **1101**, **1102**, **1103** and **1104** have been selected.

FIG. **12** shows a display, that lists by location, watch points selected for the current prediction. The designer may then select predictions for RSSI, signal to interference ratio (SIR) or signal to noise ratio (SNR). In addition, the designer can see changes in predicted values for each watch point in real time as the mouse is moved, or can choose to select new antenna positions specifically by clicking on a new location. As the designer repositions the mouse cursor, the antenna(s) selected prior to initiating the prediction are effectually repositioned and/or relocated according to position of the cursor. Once all watch points are selected, the prediction model is run. An alternative embodiment is that watch points could be entered and modified on the fly, as the prediction model is being run, rather than defined only prior to running the model. Another alternative embodiment is that RF values at the watch points are updated continuously as the mouse is repositioned, without a click being necessary.

FIG. **13** shows the floor plan of FIG. **11** with the initial RSSI values for each watch point **1101**, **1102**, **1103** and **1104** also shown. The designer may move the antenna **1100** to a new location and monitor the same watch points for coverage. FIG. **14** shows the floor plan of FIGS. **11** and **13** with the antenna **1100** moved to a new location **1400**. The RSSI values at each watch point **1101**, **1102**, **1103**, and **1104** are automatically updated with values associated with the new location of the antenna. Alternatively, the designer may choose to modify the components within the antenna system **1100** for performance or cost reasons. FIG. **15** shows the floor plan of FIGS. **11** and **13** with a base station **1100***a* at the same location, but with a higher performance antenna component. The RSSI values at each watch point **1101**, **1102**, **1103**, and **1104** are again automatically updated with values associated with the new wireless system performance parameters.

Referring again to FIG. **10**, for RF coverage models, the coverage areas and values are displayed in function block **1005**. If so desired, the designer modifies the electrical parameters of the obstructions, or modified components of antenna systems, or modifies antenna system locations or orientation, etc. in function block **1006** before running another prediction model in function block **1001**.

Referring again to FIG. **8**, after running a number of models, the design engineer may determine that RF coverage is optimal in decision block **804**. If so, then depending

on the results either a change in the location of antenna(s) and components will be desired or possibly just a substitution of components without a location change. For instance, even though the coverage may be more than adequate, the total cost of the wireless system could be prohibitive. A method for optimizing the costs using a dynamic, real time, bill of materials management system is disclosed below. Regardless, if the wireless network as currently modeled is not deemed optimal, then the method would continue again in function block **802** to re-select the components.

Once the design is as desired, then the 3-D database holds all of information necessary to procure the necessary components in the Bill of Materials. The locations of each component are clearly displayed, and a visual 3-D representation can be viewed as a guide.

Once the communications system design is as desired, the database holds all of information necessary to procure the necessary components in the Bill of Materials. The locations of each component are clearly shown, overlaid with the physical environment, and a visual 3-D representation can be viewed as a guide.

Generating and Managing a Bill of Materials

As described above, in more detail, the invention uses 3-D computer aided design (CAD) renditions of a building, collection of buildings, or any other such environment that contains information suitable for the prediction of a communications system performance. In an RF system, estimated partition electrical properties can be extracted from radio frequency measurements already published, and/or specified by the designer at any time. Once the appropriate electrical properties are specified, an unlimited number of RF sources can be placed in the 3-D database, and received signal strengths intensity (RSSI) or carrier-to-interference (C/I) ratios can be plotted directly onto the CAD drawing.

The 3-D environment database could be built by a number of methods, the preferred method being disclosed in the co-pending application Ser. No. 09/318,841. Traffic capacity analysis, frequency planning, and Co-channel or adjacent channel interference analysis can be performed concurrently with the prediction of RSSI, C/I and other wireless system performance measures. The antenna system and bill of materials could be built by a number of methods. The preferred method for building the antenna system is described above.

As the designer builds a model of a wireless communications system in a specified environment, as described above, a full bill of materials is maintained for every drawing in the environment. That is, each drawing may contain its own unique set and arrangement of antennas, feed systems and related components representing a variation in the design of a wireless communication system. These components are drawn from a global parts list library. A number of methods could be used to generate the global parts list library, and it would be apparent to one skilled in the art that varying formats could be used.

In the present invention, the design engineer selects a specific wireless system hardware component from the parts list library using pull-down menus and displayed dialog windows. The selection criteria for a particular component is wireless system design dependent, but generally involves the desirability of a component based upon its electrical characteristics and potential effect on wireless system performance, material cost, and/or installation cost. The present invention enables the designer to narrow the focus of component selection to only those devices contained within the parts list library that have the desired characteristics. For example, the design engineer may choose to design a wireless system using components from a specific manufacturer or set of manufacturers that have a desirable material cost and/or electrical characteristics. In doing so, only those devices that meet the requested criteria are displayed for selection from dialog windows in the present invention.

In certain instances, the operating frequency of a wireless communication device may define the electrical characteristics of the device. For example, depending on the frequency of the radio signal passing through an amplifier, the amplifier could have a varying amount of gain. Likewise, the radiating characteristics of antennas differ depending upon the frequency of the radio signal being broadcast. Coaxial cables, connectors, splitters, and other wireless communication system hardware components can also share this property of frequency dependent performance. To accommodate this, the parts list library from which the wireless communication system components are drawn may contain frequency specific information for each component. For example, an amplifier may have its gain specified for both 800 megahertz and 1900 megahertz. If this information is available within the parts list library for a component, the present invention automatically utilizes the frequency varying performance characteristics of the wireless hardware components within the performance prediction calculations as described below. The frequency of operation, in this case, is obtained from the transmitting source that is providing the radio signal to the wireless hardware component. For example, the base station or repeater to which the wireless hardware component is attached will have a range of frequencies or channels that it operates upon. In this case, the frequency of operation of the repeater or base station determines the frequency of the radio signal input into the wireless hardware component, and the frequency of the radio signal is in turn used to determine the operating characteristics of the component.

In addition to frequency dependent characteristics, many wireless communication devices have limitations in the manner in which they may be connected within an antenna system. Certain wireless communication hardware components are incompatible with other components and may not be connected together. For example, a fiber optic cable may not attach directly to a coaxial cable. Instead, a fiber optic cable would first connect to an optical-to-radio frequency converter device, which converts the data stream from optical into a radio signal. The coaxial cable would then connect to the output port on the optical-to-radio frequency converter. In the preferred embodiment of this invention, such connectivity restrictions are specified within the parts list library. Thus, the system automatically utilizes the information to prevent the designer from interconnecting incompatible components. If the designer attempts to interconnect two incompatible components, the present invention provides appropriate warning messages to notify the designer of the error.

Practicing communication network engineers spend tremendous amounts of time in the design and deployment phase trying to configure proper connections between communication components, such as coaxial cables, optical cables, adapters, antennas, routers, twisted pair cables, leaky feeder antennas, base stations, base station controllers, amplifiers, attenuators, connector splitters, antenna systems, repeaters, switches, wireless access points, cable boxes, signal splicers, transducers, couplers, splitters, convertors, firewalls, power distribution lines, hubs, and other communication components that are known and understood by

network engineers working in the cable, optical, wireless, networking and telephone industries. Often, various manufacturers make different brands of equipment, that are designed for particular frequency bands, mounting conditions, temperature conditions, and connector types. For example, radio frequency (RF) components often have N-connectors or SMA connectors which may not be interconnected without a proper adapter, and cables must have the proper type of connector in order to properly interconnect with other components. Similar connector types and sizes of connectors and cables exist for various makes and models of optical fiber cables, baseband twisted pair and CAT-3 and CAT-5 cables, radio frequency connectors and cables, and all other components listed above. Furthermore, network designers are often concerned about specific cost limitations, not just of a single device, but a connection of components, and often the entire system design. What's more, designers must avoid the improper mismatch of physical attributes, such as the improper connection of a very heavy component (say a switch box or a power amplifier) to a lightweight mounting fixture or a lightweight cable (say RG-58/u) that is unable to support the weight, temperature, or windload, for example. Also, particular network installations may be required in environments that have small size, low temperature, low or unusual power, or asthetic requirements, or other particular requirements that take into account the physical attributes of the components within the network design. One skilled in the art of design and deployment of communication networks is aware of other examples as taught here that typically arise in practical network design and deployment.

In addition, engineers and technicians often have particular brands or makes of products that they are required or wish to use in all of their designs. For example, their employer may insist that only certain brands be used for all deployment and design. Or, specific model numbers or series of part numbers may be required in a design. The specification and proper matching of brands or part numbers for the design of a network, which we term "brand choice", is important for desired results in many practical settings. Furthemore, components within a communications network must have compatable power connections (e.g., an RF distribution system would want to have active components that all use the same DC voltage, so that multiple power distribution lines would not have to be run), and components must be properly matched in size, weight, mounting configuration, impedance, and color. Also, designers must be sure that when they create a network design, components which they specify must have comparable maintenance requirements. For example, a designer should not create a network that requires some components to have constant maintenance, whereas others require only infrequent inspection and tuning (a mismatch in maintenance requirements).

On an even broader scale, it is helpful to have a simple checking method for making sure that components are properly designed to match the gross physical media of the various components. Some network components use and transfer or process optical frequencies (lightwaves), while others use radio frequency (RF), such as millimeter, UHF, VHF, or microwave signals, or baseband signals (VHF and below). Telephone cable, 10 baseT, twisted pair or CAT-5 type signaling is typically baseband, for example. Components which are modeled in the present invention can take in optical signals and transform them into RF or baseband signals. Similarly, some components take in RF signals and convert them to optical signals. In the design and deployment of a network, it is vital that optical cables be connected directly to optical sources, as opposed to RF or baseband signal sources. Otherwise, a network will not work. Other devices which take input signals that are at RF and produce output signals that are at optical frequencies exist. In addition, components that convert or transduce baseband-to-optical, or any other of a number of combinations of these various gross frequency bands. Physical media, which also may be called modality, may include the cables used in the network design, or may actually describe the processing components that receive and transmit at the different gross frequencies.

Components may not have compatible frequency ranges of operation, so that one part is designed for 800–950 MHz while another is designed for 1900–2100 MHz (or 200 nm vs. 300 nm, etc.). Components might have incompatibilities at the level of specific connectors, so that a connector on one component could connect with specific connectors on a specific component, but not with other connectors. Components also may require the connection of other specific components directly to them, or the presence of specific other components in the antenna system, RF distribution system, and power supply distribution system, in order to function correctly. Conversely, components may not allow the presence of specific other components, or of components from some manufacturers, to be connected directly to them, or even to be present anywhere in the design.

All of the above network design considerations are important for a designer or installer. Also, all of the individual connectors on each component within a network, as well as each frequency or gross frequency band used by each component and each connector on each component, needs to be properly tracked and must all be used and properly terminated for an effective network.

The above issues are all addressed in the present invention. Failure to meet any of the above desired criteria can be considered to be a "fault", wherein a fault can be detected automatically by the present invention in the design or deployment phase. Thus, desired cost, proper connectivity, proper matching of physical attributes, and proper connection of brands, part numbers, or manufacturers, can be readily detected and properly implemented with ease. Other faults, which follow the same logic as described above would fall within the scope of ths invention. When proper criteria are met, a fault will not be indicated, and the components within the design are used for computation of predictions of network performance. Also, the predictions of performance in a proper design may be compared directly to other designs within the same environment, as well as with actual measured field data.

Similarly, many wireless communication devices have limitations on the signal power that may be input into them. For example, an amplifier may only function properly if the input signal to the amplifier does not exceed a certain level of power. In the present invention, the power of a signal supplied to a wireless hardware component is determined to be the output power of the radio signal leaving the device to which wireless hardware component is attached within the antenna system. Typically, wireless communication system hardware components have gains and/or losses such that when a radio signal passes through a component, the radio signal is either amplified or attenuated depending on the operating characteristics of the component and the frequency of the radio signal. For example, referring to FIG. **4**, one of the omnidirectional antennas **403***a* is attached to a coaxial cable **402**, which in turn is attached to a transmitter **107** via a splitter **401**. If the transmitter **107** is transmitting with a signal power of 10 dBm, and the total loss of the

splitter **401** is 4 dB, the input signal power into the coaxial cable **402** is 6 dBm (the signal power of the transmitter minus the total loss of the splitter). Similarly, if the total loss of the cable **402** is 2 dB, the input signal power into the antenna **403***a* is 4 dBm. In the preferred embodiment of the invention, the parts list library contains information regarding the restriction of input signal power into a component. This allows the system of the present invention to notify the user of the fault in the design via displayed computer dialog boxes if, given the present configuration of the antenna system that has been visually configured and interconnected in the 3-D environmental model, that the input signal power into any of the wireless communication system hardware components exceeds the limits specified in the parts list library. This immediate feedback is invaluable to the designer and provides instant recognition of potential problems in the configuration of the antenna system.

Similarly, many cable components used in wireless communication systems have limitations on the total length of any single segment of the cable. For example, a single segment of a specific fiber optic cable may not have a length exceeding 500 feet in order to maintain the integrity of the signal passing through it. In the preferred embodiment, the parts list library will contain such length limitations specified for cabling components. Therefore, if the designer visually configures a segment of cabling within a wireless communication system such that the total length of the segment exceeds the maximum cable length specified for the cable component within the parts list library, a warning message concerning this fault in the design is displayed to the designer via computer generated dialog boxes stating the error. The total length of the cable segment is determined from the manner in which the designer has positioned the cable within the 3-D environmental database. For example, referring again to FIG. **4**, the length of the coaxial cables **402** in the figure is determined on the basis of their physical placement and orientation within the 3-D environmental model. This immediate feedback provides invaluable information to a wireless system designer as it prevents potential errors in the wireless communication system design. The maximum length restriction applies to all varieties of cabling components, such as coaxial cables, fiber optic cables, leaky feeder antennas, and any other type of wireless hardware cable.

Other limitations of a component may be imposed. The component may need to be within a certain distance from a base station, regardless of intervening components. A component may need to be a certain height above ground level, within a certain distance from a wall (internal or external) or from a high-voltage power supply source, or placed in a room of sufficient size. A component may be illegal for use in a given location, or unavailable from the manufacturer from a given ordering location. A component may be too large to fit through existing apertures providing access to an indoor location as modeled in the 3-D environment database above. A component may be too heavy for a floor, or too lightweight for an unattached position. A component may be the wrong size, color, or shape. A component may be unsuitable for environmental conditions at a given indoor or outdoor location. Components made by specific manufacturers may be unsuitable. Components exceeding a percomponent price limit may be unsuitable for a given design; such limits may be set for a given type of component e.g. amplifier, antenna, or cable, or may be set for any type of component. One skilled in the art could formulate many other obvious attributes that could also be checked for faults in a design, in the same manner.

A component may be marginally compatible with a given antenna system and RF distribution system for a given site. Manufacturer-specified warnings, maintained with other component characteristics in the component library, could be delivered appropriately for these situations. For example, a manufacturer may specify that a given component may be used at a given power level and perform properly, but that the engineer should be warned that the component will have a reduced operational lifetime, or may perform in a suboptimal manner, or cause damage to other connected parts, if used at the current input signal strength level. One skilled in the art would understand that this extends to other fault warnings about other marginally suitable components.

The present invention stores these fault warnings and the relevant conditions under which the warnings apply, in the parts list library, and automatically compares the conditions in which a component is placed in an antenna system and RF distribution system in a 3-D model of a wireless network site, and if the conditions match, displays a fault warning dialog window (not shown) to the user containing the manufacturer's warning, which must be dismissed and/or printed before the engineer is allowed to proceed with the design.

In the present invention, a cost limitation may be imposed on a given design, such that when the engineer places a component which would cause the total cost of the installation, or a portion of the installation (which is tracked in real time as indicated above) to exceed the limit, a fault warning is given. At this point, components which are relatively expensive, or inexpensive components appearing repeatedly in the design, might be identified automatically by the system as candidates for replacement for cheaper parts.

FIG. **19** shows a high level schematic of one mechanism which may be used to provide the design engineer with information on system performance and cost information. In block **1800**, he selects components which will be used in the computerized model of the physical environment in which the communications network is or will be installed. There will be a plurality of different types of components which can be selected (e.g., splitters, antennas, transmitters, base stations, cables, etc.), and there will be a plurality of models of the types of components selected (e.g., various types of fiber optic cables, coaxial cables, antennas, etc.). The components will have various attributes **1802** (e.g., type of signal carried (i.e., optical or radiowave), maximum propagation length (for cables), etc.), frequency characteristics **1804** (e.g., electrical properties of a component at two or more frequencies, etc.), and cost **1806** information associated with one or more components which are selected in decision block **1800**. The selected components will then be displayed on the computerized representation of the physical environment in which the communications system is or will be installed in block **1808**. The system will automatically determine, based on the attributes **1802**, whether the components selected can properly work together as intended by the designer or whether the components will satisfy all of the demands required of them in the communications system designed by the designer or any other error which may be present in the communications network at decision point **1810**. If the communications network will not perform properly, the designer will be notified of the fault(s) in the design by a display on the screen, audible warning, or other effective means at block **1812**. This will allow the designer to go back and select more suitable components. If there are no faults in the design proposed by the designer, one or more prediction models will be run at block **1814**, and the results

of these calculations will be displayed to the designer at block **1816**. If changes in frequency parameters are to be considered in the prediction models, this can be done at block **1818**. If desired, the cost of the componentry used in the communications network designed by the designer can be provided in a bill of materials at **1820**.

In addition, in the preferred embodiment the parts list library contains specifications for compound components, hereafter referred to as "component kits." A component kit is a predefined group of select individual wireless communication components which may or may not be partially or wholly interconnected and arranged. Component kits are specified separate from a 3-D environmental model and are not related to the physical layout of a facility. For example, a component kit could consist of a specific splitter connected with a specific cable, which in turn is connected with a specific antenna. The component kit does not define where in the 3-D environmental model the splitter, cable, and antenna are positioned, but simply identifies that they are connected or assembled together. The designer may then select the component kit itself in exactly the same manner as any other individual hardware component and position the complete kit within the 3-D environmental model. Thus, by selecting the kit and positioning it within the 3-D environmental model, the designer has automatically selected and positioned the splitter, cable, and antenna.

An important and novel capability of the present invention is the ability to provide communication network performance predictions that use the component kits, and to allow such predictions to be compared with measured network data. In practice, actual communication networks may be configured using system components which are configured in a specific manner, and this specific physical and electrical representation may be done approximately or completely in its entirety by a component kit. Component kits also contain much more detailed information of each component or subsystem within the kit, such as physical media specifications for proper gross frequency interconnection, physical attributes, cost, depreciation and maintenance schedule information, so that proper interconnections within a kit, and from one or more kits to another kit, or from one or more kits to a network, may be made without a "fault", as described herein. Measurements made from actual systems comprised of components that are modeled either exactly or approximately in a component kit within the present invention may be displayed, stored, and compared directly to predictions made by systems designed with the component kit.

Referring to FIG. **20**, there is shown a representation of the component kit computer editing window in the preferred embodiment of the invention. In FIG. **20**, a component kit named "Component Kit #1" **1001** is shown. The component kit represents five individual components that are interconnected in a certain fashion. A coaxial cable **1002** is connected with a splitter **1003**. One output connector of the splitter connects to an antenna **1004**, while the other output connects to a leaky feeder antenna **1005**. The leaky feeder antenna then terminates **1006**. The computer editor window **1007** graphically portrays the interconnection of the various components, and enables the designer to add or remove components to the component kit. Once created, the component kit **1001** can be selected and positioned within the 3-D environmental model just as any individual component. For example, FIG. **21** shows each of the components **1002**–**1006** of component kit **1001** positioned in one room of a three dimensional floor plan. The design engineer can then connect other components in the communications network, but also may select other groups of components or "component kits" for use in the facility defined by the three dimensional floor plan (or multistory facility or campus wide communications network). This enables the designer to quickly place multiple components in the 3-D environmental model by enabling the multiple components to be selected as placed as a single component.

Once a desired component is selected by pointing and clicking with a mouse or other input device (components and component kits may be imported, exported, and exchanged electronically and textually between users in the preferred embodiment of the invention), the design engineer may position the component within the three dimension environmental database. This process involves the design engineer using the mouse or other input device to visually identify the desired location for the component by clicking (or otherwise identifying) positions within the 3-D environmental database. For example, an antenna component could be placed within a specific room of a building, atop a flag pole on the side of a building, in the center of a park, or any other location deemed reasonable by the designer. In similar fashion, hardware components that span distances (e.g. coaxial cable, fiber optic cable, leaky feeder antenna, or any component having substantial length) are selected and positioned within the 3-D environment by clicking with the mouse or other input device to identify the vertices (or end points) of the component where each pair of vertices are connected by a time segment representing a portion of cable. Thus, while certain components, such as point antennas or splitters, for example, require only a single point in the 3-D environment to identify placement in the wireless communication system, other components such as distribution cables or distribution antennas require the identification of multiple points joined by line segments to identify placement. In the present invention, unique graphic symbols are utilized to represent each wireless system component and overlaid onto the three-dimensional environmental database enabling the designer to visualize the wireless communication system as it would exist in the physical world. As an example of the graphical display and shown only in two dimensions for convenience, FIG. **4** displays a base station **107** connected via two coaxial cables **402** to two indoor point antennas **403***a* and **403***b*.

The present embodiment of the invention provides and links information relating to wireless system component dependence. Such dependencies may include but are not limited to impedance matching of adjoining components, maximum run length, proper termination, or some other fault, as described herein. Certain components in the parts list library may require pre-existing components to have been positioned within the 3-D environmental database before they themselves may be selected and added to the wireless system. For example, a splitter or other device designed to interconnect two or more independent components may require that an existing component be present in the three dimensional database for the splitter to be connected with. In the previous embodiment of the invention, if the designer chooses to place a hardware component within the 3-D environmental database, and the desired component is dependent upon some other device currently placed in the 3-D database, the designer is prompted through a selection window to identify the dependent component and the selected component is positioned accordingly. In the previous example of the splitter component, if the designer chooses to connect the splitter onto the end of an existing cable component by identifying the cable component with the mouse or other input device, the position of the splitter

within the three-dimensional database is automatically assigned to be the end of the identified cable. In this way the invention helps prevent the user from creating faulty designs. Wireless system components that do not have such dependencies (e.g., base station transceivers) may be freely positioned anywhere within the 3-D environmental database that is deemed suitable by the designer. As this description is specific to one particular implementation, one skilled in the art could see how different implementations could be developed and practiced within the scope of this invention.

In the preferred embodiment of the invention, if the wireless communication hardware components have information specified within the parts list library detailing restrictions on, for example, maximum input signal power, maximum length, or connectivity restrictions, the present invention will notify the designer immediately if any of these restrictions or limitations are exceeded during the course of the design. This notification of a potential fault occurs via computer generated dialog boxes containing textual warning messages detailing the restriction or limitation being exceeded with the present configuration of the wireless communication system within the 3-D environmental model.

Using the preferred embodiment of the invention, a designer can model and represent, visually as well as mathematically, complex wireless communication systems involving any number of individual hardware components selected from the parts list library, interconnected with and linked to one another to form complete antenna systems. As each component has associated characteristics regarding electrical properties (e.g. gain, noise figure, attenuation) and cost, the addition, removal, or change of any component directly impacts both the performance of the wireless system and the overall system cost. With the preferred embodiment of the invention, this information is updated in real-time as the designer makes changes to the wireless system. If a wireless communication system includes a specific hardware component, the present invention retrieves the associated electromechanical characteristics and other pertinent information from the parts list library entry that has been specified for the component. This information is stored in a database and is then used to quantify the effect that the component has on various aspects of wireless system design parameters or performance. For example, if the parts list library information for a specific cable indicates that the attenuation loss of the cable is 3.5 dB per 100 meters, and the designer has added a 200 meter segment of the cable to the wireless communication system, the present invention combines the information regarding the placement and length of the cable in the 3-D environmental database with the attenuation loss information from the parts list library to determine a total attenuation loss of 7 dB for the cable. Furthermore, the noise figure and other related qualities of the cable is also computed based upon well known communication theory. If the designer then adds an amplifier to the wireless system and connects it onto the end of the cable as described above, the invention retrieves information regarding the amplifier from the parts list library to determine overall gain of the wireless distribution system. If, for instance, the selected amplifier has an associated gain of 10 dB and some specified noise figure, the present invention combines the characteristics of the interconnected cable and amplifier to determine a total gain of 3 dB for the combined components, and a new system noise figure. If the designer edits or alters component information in the parts list library, this is automatically reflected in the wireless system performance prediction. For example, if the amplifier in the example above has the gain associated with it edited in the parts list library and changed from 10 dB to 15 dB, the combined system characteristics, which may include but are not limited to system gain and system noise figure, of the cable and amplifier from the example are automatically recalculated, resulting in an overall gain of 8 dB instead of 3 dB. Similarly if the cable is repositioned such that its overall length is altered or replaced with a different component from the parts list library, the effect of doing so is automatically recalculated an reflected in all future operations.

As mentioned previously, the Parts List Library preferably contains information regarding the frequency dependent nature of a wireless system component, the operating characteristics of the component utilized during the calculation of gains, losses, noise figure, or any other qualities that utilize the frequency of the input signal into the component to determine the specific set of operating characteristics for the component. If the component does not have a set of parameters defined for the desired operating frequency, the present invention searches for and uses the set of operating parameters specified for the frequency closest to the actual frequency of the input signal. This is a very powerful feature of the present invention as it enables a designer to select components for use in a wireless communication system without the need to worry about the operating parameters of the component relative to the operating frequency of the wireless communication system. The present invention automatically uses the best set of frequency dependent parameters specified for each wireless hardware component based on the frequency of the input signal to the component.

The Parts List Library, or component library, of the present invention also contains information regarding operating characteristics of a component which depend on some combination of the frequency of the input signal to the component, the connector on the component to which the input is applied or through which output is passed, and the direction of the signal, i.e., forward link from the base station to the mobile receiver or reverse link back to the base station from the mobile receiver. The preferred embodiment specifies a coupling loss that applies to a particular component, for a particular frequency range and modality, for a particular connector on the component, for a particular directionality of signal (i.e., forward link or reverse link). A different coupling loss is specified explicitly (or may be derived automatically) for each combination of connector, supported frequency band (of which a given component may have many), and directionality. These values are preferably applied automatically in real time to the aforementioned system performance predictions, according to the active frequency of the signal arriving at and/or leaving a component, the connector on which the modeled signal arrives at and/or leaves the component, and whether the forward link or reverse link performance is being evaluated. One skilled in the art could implement additional specifications dependent on combinations of the frequency, connector, directionality, or other aspects of the signal applied to a component.

Although the given example is in terms of simple gains and losses of the individual wireless components, one skilled in the art could apply this same method to any other electrical, electromechanical financial, aesthetic or other quality associated with components in the parts list library and the overall system in a similar fashion.

A preferred Parts List Library is designed to be generic and applicable to any type of wireless communication

system component or wireless communication system design methodology. There are eight basic categories of components in the preferred parts list library utilized in the preferred embodiment, although more categories could be added, as desired:

1. Amplifiers/Attenuators—generally speaking, devices that either boost or decrease the strength of radio wave signals;
2. Connectors/Splitters—generally speaking, devices that connect one or more components to one or more additional components;
3. Cables—various types of cabling (e.g., fiber optic cable, coaxial cable, twisted pair cable, etc);
4. Manufacturer-Specified Point Antennas—any antenna that is manufactured and whose manufacturer has supplied information with regard to the radiation pattern of the antenna. The radiation pattern of an antenna describes the manner in which radio signals are radiated by the antenna. Antenna manufacturers supply radiation pattern information regarding their antennas so that wireless system designers can maximize the effectiveness of antenna deployments;
5. Generic Point Antennas—any generic or idealistic antenna (that is, an antenna that may not be physically realizable or has a generic radiation pattern);
6. Leaky Feeder Cabling/Antennas—a type of antenna that takes the form of a specialized coaxial cable;
7. Base Station/Repeater—the controlling portion of the wireless communication system. The base station manages all communication taking place in the wireless network;
8. Component kit-one or more individual components interconnected or grouped interconnected together to form a compound component (this preferably being done within the discretion of the design engineer by selecting amongst all or some of the components in the Parts List Library to define one or more component kits made of selected components). The component kit is referenced as a single hardware component and enables the designer to quickly add and manipulate multiple wireless hardware components. It preferably has no directly assigned electromechanical properties defined in the Parts List Library; however, the individual hardware components contained within the component kit retain all electromechanical properties assigned to them within the Parts List Library; and
9. Other—Any component that does not belong in one of the above categories.

Each component has a variety of associated values. These include, but are not limited to:

Manufacturer Name;

Manufacturer Part Number;

User-supplied Description;

Frequency range at which part has been tested;

Attenuation/Amplification;

Number of Connections;

Physical Cost (material cost of component);

Installation Cost;

Antenna Radiation Pattern;

Maximum input signal power;

Maximum length (for cables);

Modality of component type (e.g., optical, radio signal, etc.)

Note that many or all of the associated values listed above could vary depending on the frequency of the input signal to the component. They may also depend on the combination of input signal frequency, connector on the component to which the signal is applied or via which the signal exits the component, and whether the signal is a forward link signal originating at the base station, or reverse link signal originating from a user of the system. The parts list library utilized in the preferred embodiment of the invention allows the amplification/attenuation, radiation pattern, and maximum input signal power to be identified for specific frequencies of frequency ranges for each wireless hardware component. The coupling loss varies by frequency, connector, and direction of signal (forward or reverse link), in the preferred embodiment.

Base stations and repeater components have a number of additional parameters associated with them, including, but not limited to:

Technology/Air Interface—identifies the wireless technology employed by the base station (e.g., AMPS ("analog cellular"), IS-136 ("digital cellular"), IEEE 802.11 ("wireless LAN"), etc.);

Frequency/Channel Assignments-identifies the radio frequencies/channels this base station can utilize; and

Transmit Power—the amount of power the base station is broadcasting.

An excerpt from the preferred embodiment of a parts list is shown below.


```
<ComponentSpec>
    <databaseKey>5110</databaseKey>
    <name><![CDATA(Ultraflexible Series Cable]]></name>
    <type>CABLE</type>
    <manufacturer><![CDATA[Bob's Cables and
        Connectors, Inc.]]></manufacturer>
    <partNumber><![CDATA[Model 21-A]]></partNumber>
    <purchaseCost>0</purchaseCost>
    <installationCost>0</installationCost>
    <maximumLength>none</maximumLength>
    <fileDescriptor><![CDATA[N/A]]></fileDescriptor>
    <otherInfo><![CDATA[N/A]]></otherInfo>
    <connectorCount>2</connectorCount>
    <bandList>
        <BAND>
            <modality>R</modality>
            <minFreq>4e+008</minFreq>
            <maxFreq>4e+008</maxFreq>
          <inputSignalMaxFwd>none</inputSignalMaxFwd>
          <inputSignalMaxRev>none</inputSignalMaxRev>
        <outputSignalMaxFwd>none</outputSignalMaxFwd>
        <outputSignalMaxRev>none</outputSignalMaxRev>
            <insertionLoss>7.42</insertionLoss>
            <associatedConnector>
                <number>0</number>
                <couplingLossFwd>0</couplingLossFwd>
                <couplingLossRev>0</couplingLossRev>
            </associatedConnector>
            <associatedConnector>
                <number>1</number>
                <couplingLossFwd>0</couplingLossFwd>
                <couplingLossRev>0</couplingLossRev>
            </associatedConnector>
        </BAND>
        <BAND>
            <modality>R</modality>
            <minFreq>4.5e+008</minFreq>
            <maxFreq>4.5e+008</maxFreq>
          <inputSignalMaxFwd>none</inputSignalMaxFwd>
          <inputSignalMaxRev>none</inputSignalMaxRev>
        <outputSignalMaxFwd>none</outputSignalMaxFwd>
        <outputSignalMaxRev>none</outputSignalMaxRev>
            <insertionLoss>7.87</insertionLoss>
```

-continued


```
                <associatedConnector>
                    <number>0</number>
                    <couplingLossFwd>0</couplingLossFwd>
                    <couplingLossRev>0</couplingLossRev>
                </associatedConnector>
                <associatedConnector>
                    <number>1</number>
                    <couplingLossFwd>0</couplingLossFwd>
                    <couplingLossRev>0</couplingLossRev>
                </associatedConnector>
            </BAND>
            <BAND>
                <modality>R</modality>
                <minFreq>7e+008</minFreq>
                <maxFreq>7e+008</maxFreq>
                <inputSignalMaxFwd>none</inputSignalMaxFwd>
                <inputSignalMaxRev>none</inputSignalMaxRev>
                <outputSignalMaxFwd>none</outputSignalMaxFwd>
                <outputSignalMaxRev>none</outputSignalMaxRev>
                <insertionLoss>10</insertionLoss>
                <associatedConnector>
                    <number>0</number>
                    <couplingLossFwd>0</couplingLossFwd>
                    <couplingLossRev>0</couplingLossRev>
                </associatedConnector>
                <associatedConnector>
                    <number>1</number>
                    <couplingLossFwd>0</couplingLossFwd>
                    <couplingLossRev>0</couplingLossRev>
                </associatedConnector>
            </BAND>
        </bandList>
</ComponentSpec>
```


This excerpt from the parts list of the present invention is the complete specification of a single component. The excerpt is in XML format, and each element of the specification is labeled with XML tags. The <ComponentSpec> tag begins the component, the <databaseKey> tag indicates the internal database key used to index the part, and the </databaseKey> ends the value for the internal database key. Similarly, the specifications include the manufacturer identified by <manufacturer>, the part name identified by <name>, and so on. There is also a list of frequency bands, marked off by a <bandList> tag. Each band, demarcated by a <BAND> tag, contains specifications which apply only when the signal applied to the component is closest to the particular band. For a band, the modality (e.g. optical, RF, baseband, CAT-5) is indicated with a <modality> tag, and symbolized by 'R' for RF, 'O' for optical, etc. The minimum and maximum frequency that bound the band are marked by <minFreq> and <maxFreq> tags; the signal maxima for input and output, forward and reverse link, respectively, for the band are also defined, as is the insertion loss for the band. Finally, a list of connectors supported by the band in question appears, marked by an <associatedConnector> tag. Each set of specifications for an associated connector include the connector number as an identifier, and a separate coupling loss for the forward link and for the reverse link, identified by the <connectorNumber>, <couplingLossFwd>, and <couplingLossRev> tags.

Thus the present invention defines specifications dependent on the frequency alone; dependent on the frequency and the component's connector; and dependent on the frequency, the connector, and the link direction, whether forward or reverse.

The parts list can be easily modified by a design engineer as new components are placed on the market, removed from the market or re-priced. The ability to maintain a unique equipment list for each drawing enables the designer to carry out rapid design analyses to compare and contrast the performance and cost of different vendor components. The impact of utilizing a specific component in terms of both cost and wireless communication system performance can be seen immediately using the present invention. Information that can be tracked with the bill of materials includes the manufacturer and part number, physical and installation cost, RF loss characteristics, connections, and the frequencies for which the component is valid. In addition, a rich set of customization features is utilized to enable the designer to tailor the parts list library to suit the needs of the target application. Moreover, as components with associated length data, such as cables or leaky feeder antennas, are created, stretched, moved or modified, their associated costs and impact on wireless system performance are automatically updated in the bill of materials to account for the change in length. Furthermore, the parts list is stored as an integral part of the drawing database, allowing the user to recall and archive a system design and all of its particulars. In addition, the wireless communication system performance may be recalculated immediately, using either a standard link budget equation, noise figure equation, or some other metric such as bit error rate or network throughput. This recalculation uses the specific, perhaps frequency specific electrical specifications of each component in the system, which are also stored in the bill of materials.

Referring again to the drawings, and more particularly to FIG. **16**, there is shown an example of a bill of materials summary for a drawing. A description of the base station "MACROCELL" **1610** is shown to identify the antenna system for which the summary is shown. The first component **1611** is a PCN Panel **1710**-1990 92 Deg 9.00 dB Gain point antenna manufactured by Allen Telecom. One should note that the component cost **1612**, sub-total cost **1613** and total system cost **1614** is $0.00. This shows that the designer has not yet updated the parts list library with current costs. When the list has been updated, the summary will automatically show component costs as well as sub-totals and totals for all base stations and components in the drawing.

FIG. **17** show a bill of materials where costs have been entered into the parts list database. Another component **1720** has been added to the "MACROCELL" base station, also. The costs of each component **1612*a*** and **1721** are now shown. Sub-total **1613*a*** and Total costs **1614*a*** are also shown.

Referring now to FIG. **18**, the general method of the invention is shown. As previously described, first the designer must create a database defining the desired environment in function block **180**. A preferred method is disclosed in the co-pending application Ser. No. 09/318,841. A database of components is then developed in function block **181**. In the case of wireless communication networks, a preferred method is described above. The creation of these components will automatically generate a parts list categorized by base station and antenna system. A bill of materials may be displayed at any time in function block **182**.

In order to optimize the design of the wireless communications system and ensure adequate antenna coverage, the designer runs a series of prediction models and optimization techniques in function block **183**. A preferred method for running predictions is described above. This method allows the designer to see, in real-time, changes in coverage, generally, and for specifically chosen watch points, as antennas are repositioned or reoriented. The designer may choose to add, delete or substitute components in function block **184** and then re-run the models again in function block **183**. Each time the designer makes a modification in the system to improve performance, the bill of materials is automatically

updated. The designer may run the prediction models in function block **183**, and determine if the wireless system, as designed, is adequate in terms of performance and cost. If not, the designer can choose to modify components using cost or component performance considerations. Performance parameters may be entered to enable the designer to choose substitute components from a list that contains only those components that would not degrade the performance of the overall system. Note that in the preferred embodiment, the prediction or system performance models are recomputed upon user demand, but that it would be apparent to one skilled in the art to also have models recomputed instantly ("on-the-fly") as new components are added or subtracted from the bill of materials.

The integration of the bill of materials and component performance specifications is key to providing a quick and efficient method to design high performance wireless communication networks that are within budget. In addition to individual component physical and installation costs, a collection of components that may be interconnected or possibly used within a common network may also be specified. Such components from a component kit may be used in a design, and also may be considered for physical and installation cost. Moreover, within a bill of materials containing a list of network components, there may also be a tabulation, computation and storage of other important cost information for some of the components, such as cost depreciation values, or schedules for depreciation of particular components or groups of components. Such information may be available for only certain components within a network or within a parts list provided by a particular manufacturer. In addition, maintenance schedule information, which specifies the particular period or dates during which routine maintenance is required, may be included within the description of components within a bill of materials, to help the maintenance staff to properly maintain the designed network.

While the invention has been described in terms of its preferred embodiments, those skilled in the art will recognize that the invention can be practiced with modification within the spirit and scope of the appended claims.

Having thus described our invention, what we claim as new and desire to secure by Letters Patent is as follows:

1. A method for designing or deploying a communications network, comprising the steps of:

providing a computerized model which represents a physical environment in which a communications network is or will be installed, said computerized model providing a display of at least a portion of said physical environment;

providing performance attributes for a plurality of system components which may be used in said physical environment, a number of said system components having associated with them frequency dependent characteristics;

selecting specific components from said plurality of system components for use in said computerized model;

representing said selected specific components in said display;

running prediction models using the computerized model and said performance attributes to predict performance characteristics of a communications network comprised of said selected specific components, said prediction models utilizing said frequency dependent characteristics in calculations which predict said performance characteristics of said communications network.

2. The method of claim **1** wherein said frequency dependent characteristics define electrical properties of said system components at at least two different frequencies.

3. The method of claim **1** further comprising the step of generating a bill of materials containing cost information for said selected specific components utilized in said communications network.

4. The method of claim **3** wherein said cost information comprises a maintenance schedule for selected specific components.

5. The method of claim **1** wherein said display is three dimensional.

6. The method of claim **1** wherein said system components allow converting between radio frequency and optical frequency.

7. The method of claim **1** wherein said system components allow converting between optical frequency and baseband frequency.

8. The method of claim **1** wherein said system components allow converting between radio frequency and baseband frequency.

9. The method of claim **1** further comprising the step of identifying errors in physical media connections for two or more specific components selected in said selecting step.

10. An apparatus for designing or deploying a communications network, comprising:

a means for providing

(I) a computerized model which represents a physical environment in which a communications network is or will be installed, said computerized model providing a display of at least a portion of said physical environment, and

(II) performance attributes for a plurality of system components which may be used in said physical environment, a number of said system components having associated with them frequency dependent characteristics;

a means for selecting specific components from said plurality of system components for use in said computerized model;

a means for representing said selected specific components in said display; and

a means for running prediction models using the computerized model and said performance attributes to predict performance characteristics of a communications network comprised of said selected specific components, said prediction models utilizing said frequency dependent characteristics in calculations which predict said performance characteristics of said communications network.

11. The apparatus of claim **10** further comprising a means for generating a bill of materials containing cost information for said selected specific components utilized in said communications network.

12. The apparatus of claim **11** wherein said cost information comprises a maintenance schedule for selected specific components.

13. The apparatus of claim **10** wherein said display is three dimensional.

14. The apparatus of claim **10** further comprising a means for identifying errors in physical media connections for two or more selected specific components.

* * * * *

EXHIBIT D

US006973622B1

(12) **United States Patent**
Rappaport et al.

(10) **Patent No.: US 6,973,622 B1**
(45) **Date of Patent: Dec. 6, 2005**

(54) **SYSTEM AND METHOD FOR DESIGN, TRACKING, MEASUREMENT, PREDICTION AND OPTIMIZATION OF DATA COMMUNICATION NETWORKS**

(75) Inventors: **Theodore Rappaport**, Salem, VA (US); **Roger Skidmore**, Blacksburg, VA (US); **Benjamin Henty**, Blacksburg, VA (US)

(73) Assignee: **Wireless Valley Communications, Inc.**, Austin, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 724 days.

(21) Appl. No.: **09/668,145**

(22) Filed: **Sep. 25, 2000**

(51) **Int. Cl.**[7] **G06F 3/00**; G06F 19/00; G06F 15/16

(52) **U.S. Cl.** **715/735**; 715/736; 703/21; 703/22; 709/221

(58) **Field of Search** 703/2, 3, 5, 21, 703/22; 455/33.1, 33.4, 564, 446; 345/133; 202/186; 715/735, 736, 734; 709/221, 222

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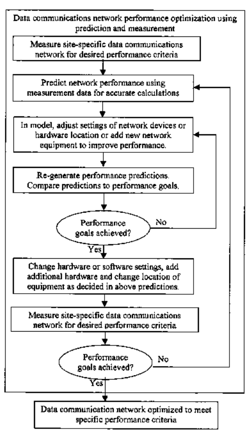
Primary Examiner—Larry D. Donaghue
(74) *Attorney, Agent, or Firm*—Whitham, Curtis & Christofferson, PC

(57) **ABSTRACT**

A system and method for design, tracking, measurement, prediction and optimization of data communications networks includes a site specific model of the physical environment, and performs a wide variety of different calculations for predicting network performance using a combination of prediction modes and measurement data based on the components used in the communications networks, the physical environment, and radio propagation characteristics.

68 Claims, 6 Drawing Sheets

Method for optimizing a data communications network using predictions and measurements.



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Company Web Page "Ericsson" www.ericsson.com product name: TEMS Lite, no date given.
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Company Web Page "Marconi" www.marconi.com product name: PlaNET, no date given.
Company Web Page "Marconi" www.marconi.com product name: deciblePlanner, no date given.
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Company Web Page "ScoreBoard" www.scoreboard.com product name: ScoreBoard, no date given.

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Figure 1: Example transmission of data over a communications network

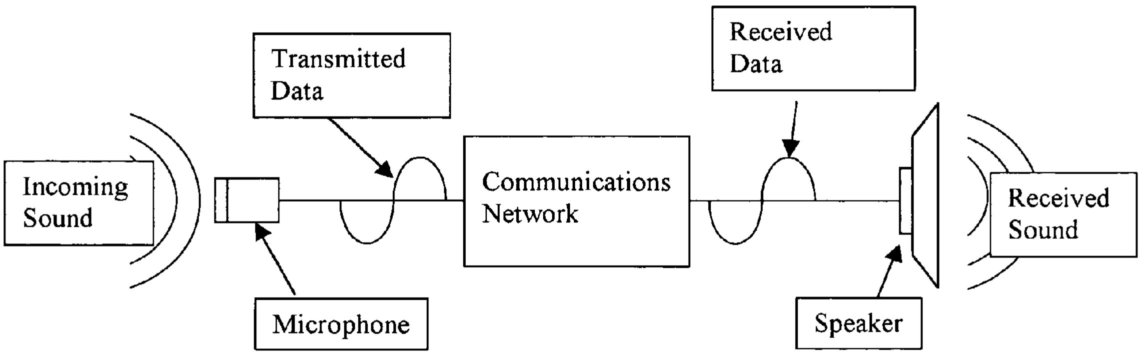


Figure 2: Creation of a digital signal from an analog signal

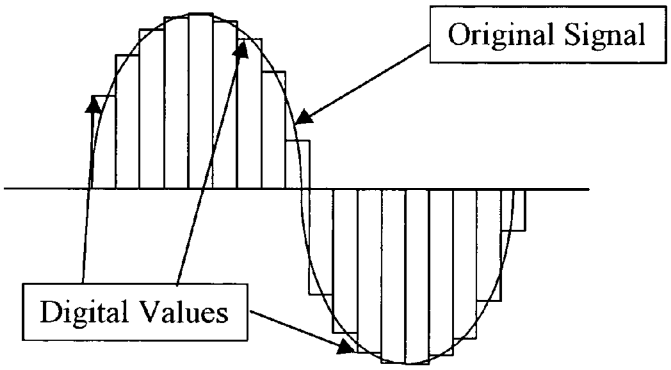


Figure 3: Illustration of the difference between bits, packets and frames.

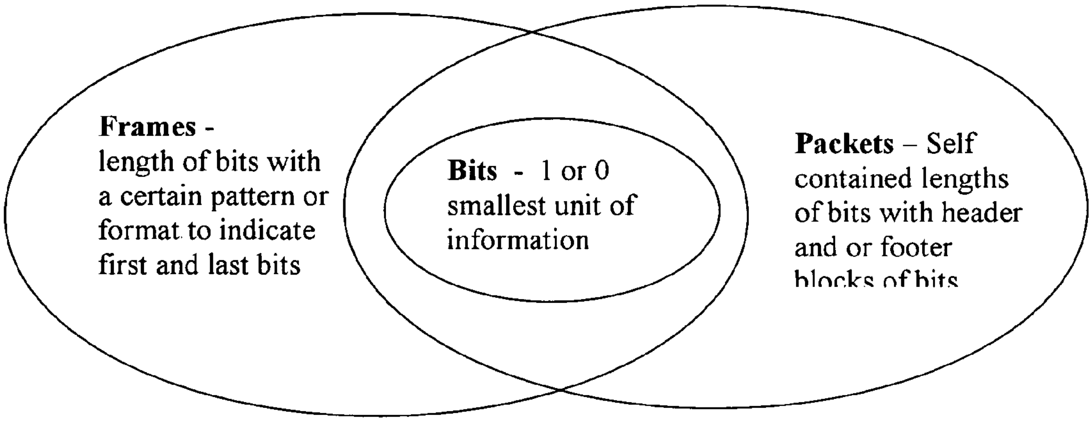


Figure 4: Illustration of the data displayed in each node of the Tree View of a data communications network.

- Name and type of network device
  - Specifications
    - Electrical, Optical, and Electromagnetic specific operating parameters
    - Software, Firmware and Hardware version numbers and settings
  - Physical connectors
    - Specifications and setting specific to each connector

Figure 5: Method for creating a 3-D site specific model of the environment

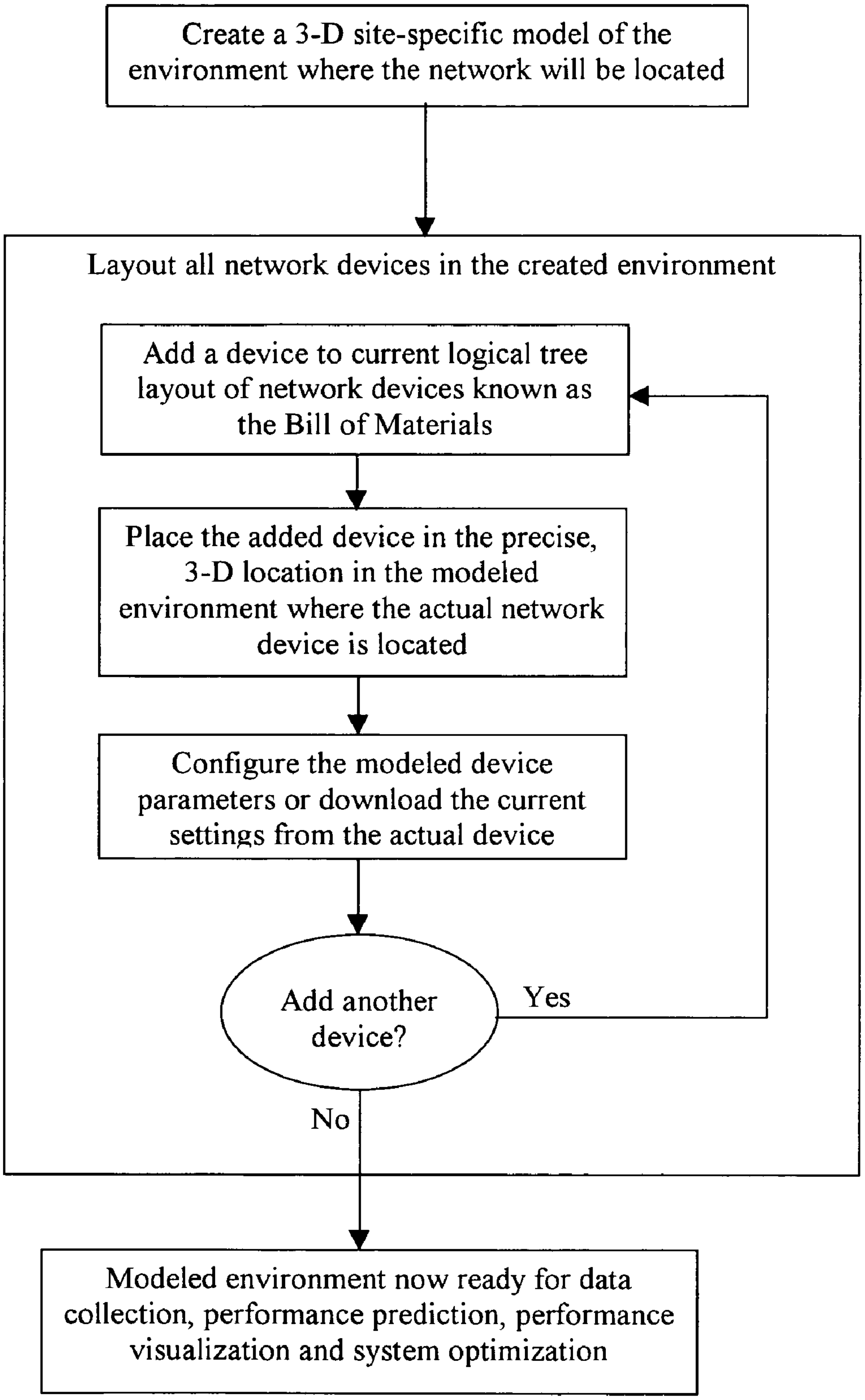


Figure 6: Method for optimizing a data communications network using predictions

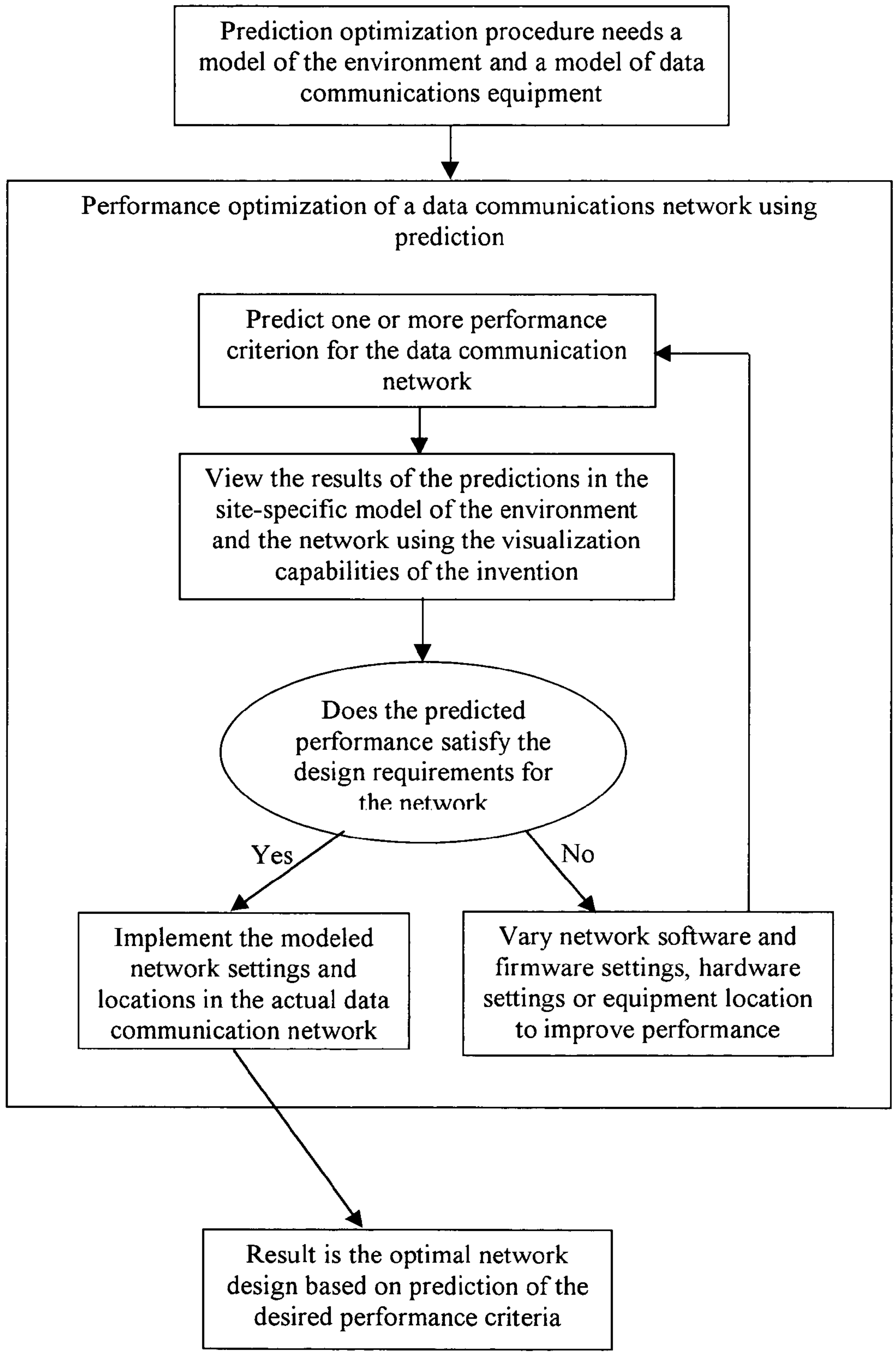


Figure 7: Method for optimizing a data communications network using measurements

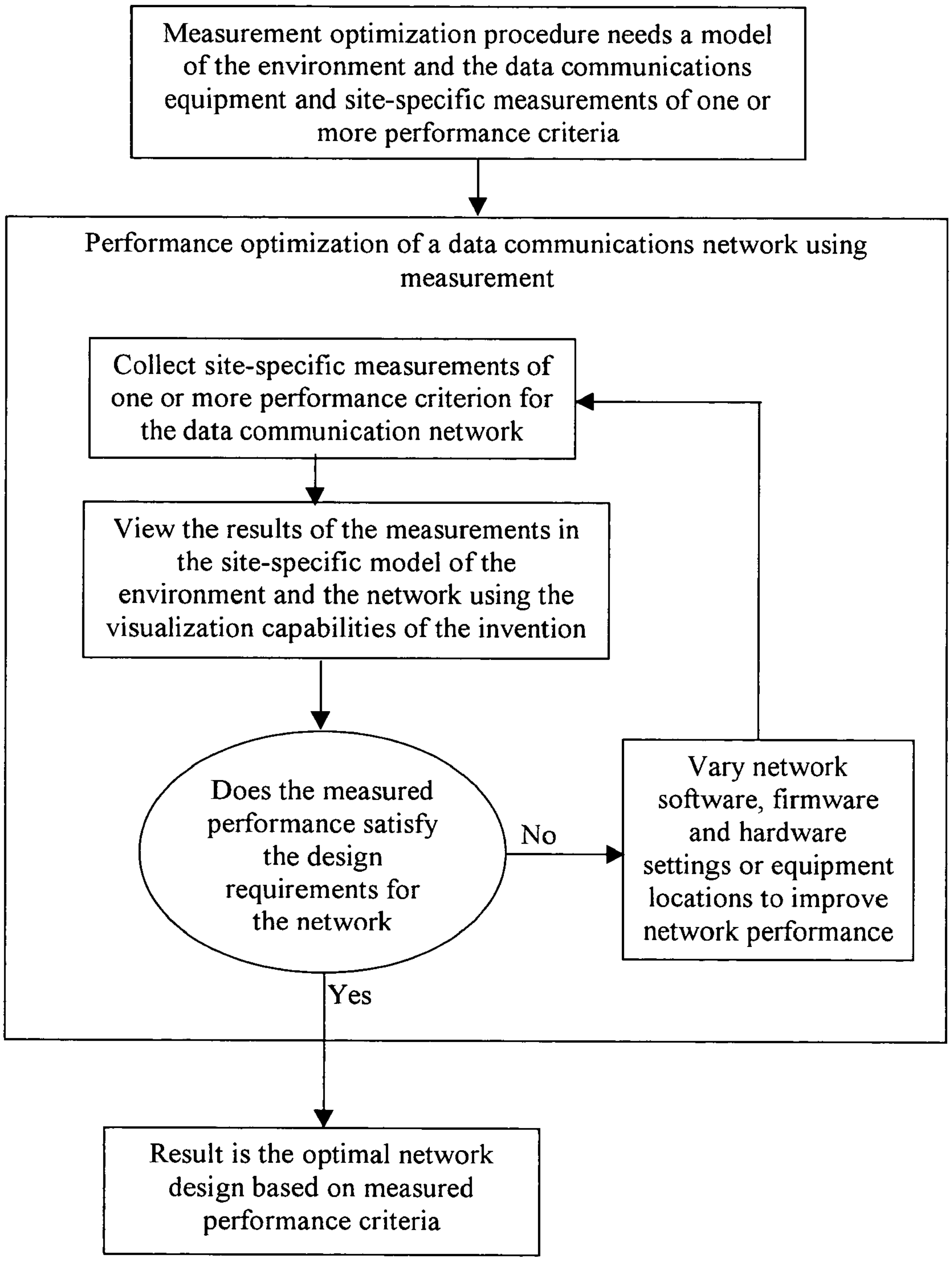
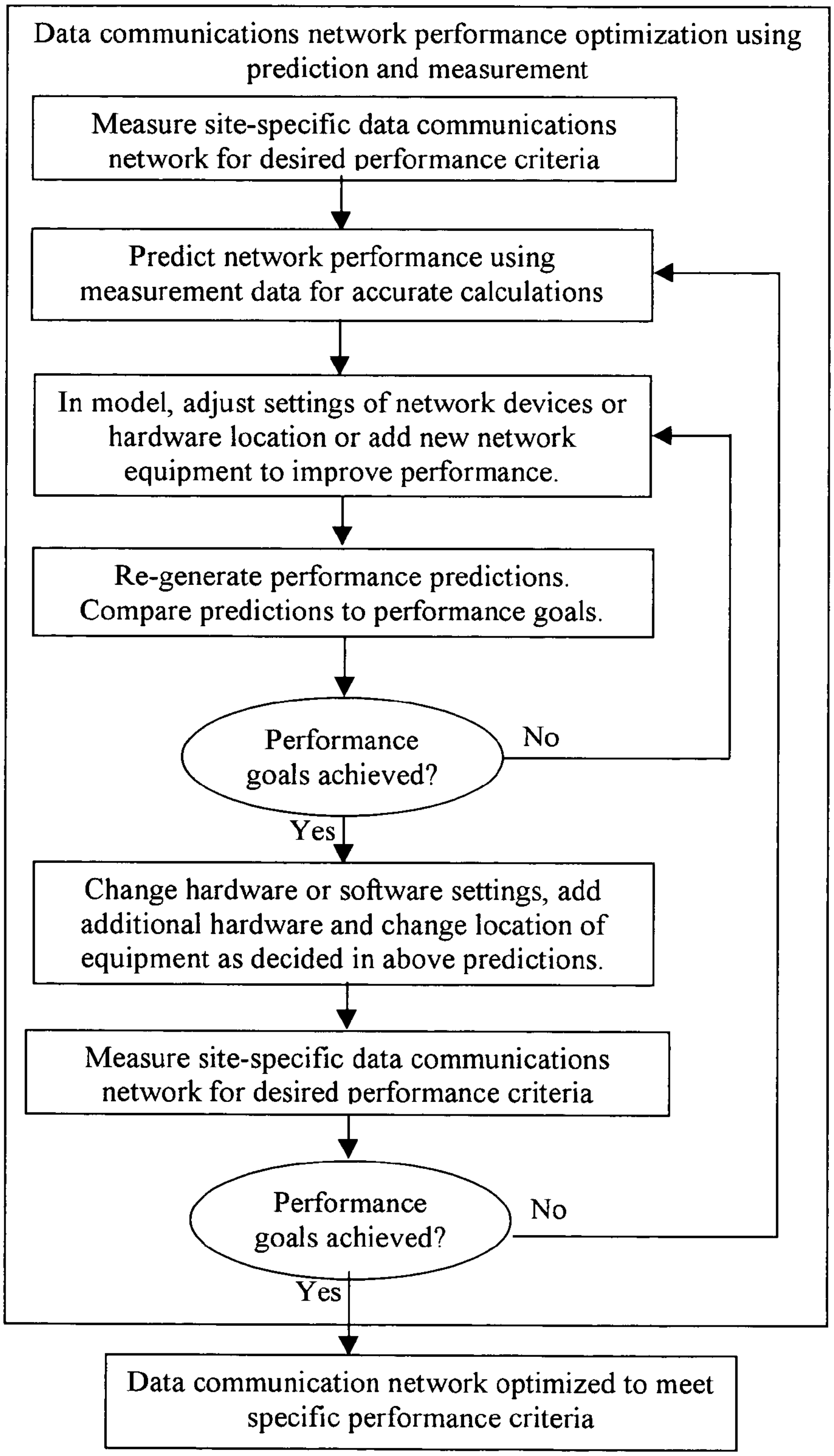


Figure8: Method for optimizing a data communications network using predictions and measurements.



SYSTEM AND METHOD FOR DESIGN, TRACKING, MEASUREMENT, PREDICTION AND OPTIMIZATION OF DATA COMMUNICATION NETWORKS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is related to application Ser. No. 09/318, 842, entitled "Method and System for Managing a Real Time Bill of Materials," filed by T. S. Rappaport and R. R. Skidmore, now U.S. Pat. No. 6,493,679, Ser. No. 09/318, 841, entitled "Method And System for a Building Database Manipulator," filed by T. S. Rappaport and R. R. Skidmore now U.S. Pat. No. 6,850,946, Ser. No. 09/318,840, entitled "Method and System For Automated Optimization of Communication component Position in 3D" filed by T. S. Rappaport and R. R. Skidmore, now U.S. Pat. No. 6,317,599. Pending application entitled "Method and System for Designing or Deploying a Communications Network which Allows Simultaneous Selection of Multiple Components" filed by T. S. Rappaport and R. R. Skidmore, Ser. No. 09/633,122, filed on Aug. 4, 2000, as well applications entitled "Method and System for Designing or Deploying a Communications Network which Considers Frequency Dependent Effects", Ser. No. 09/632,121, filed by T. S. Rappaport and R. R. Skidmore on Aug. 4, 2000 now U.S. Pat. No. 6,625,454, as pending application entitled "Method and System for Designing or Deploying a Communications Network which Considers Component Attributes", Ser. No. 09/632,853, filed by T. S. Rappaport, R. R. Skidmore, and Eric Reifsnider on Aug. 4, 2000, as well as application entitled "Improved Method and System for a Building Database Manipulator", Ser. No. 09/633,120, filed by T. S. Rappaport and R. R Skidmore, now U.S. Pat. No. 6,721,769 and pending application entitled "System and Method for Efficiently Visualizing and Comparing Communication Network System Performance", Ser. No. 09/632,803 filed by T. S. Rappaport, R. R. Skidmore, and Brian Gold on Aug. 4, 2000, and co-pending application "Method and System for Automated Selection of Optimal Communication Network Equipment Model, Position and Configuration in 3-D", Ser. No. 09/667,689, filed by T. S. Rappaport, R. R. Skidmore, and P. SheethalNath filed concurrently, the subject matter of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to the field of communications networks, and more specifically to the design thereof, and the measurement, visualization, prediction and optimization of the performance of data communication networks. A method and system to predict, visualize and optimize the performance of data communication networks is used to design, measure, monitor, troubleshoot and improve these data networks using an accurate site-specific model of the physical environment and the components comprising the data network.

2. Description of the Related Art

Communications networks are used to send information from one place to another. This information often takes the form of voice, video or data. To transmit information a communications network breaks down a message into a series of numbers. These numbers describe how to construct the information using some predetermined method. For example, the numbers could represent digital samples of the signal voltage that should be applied to a speaker so that the speaker reproduces the sound of the voice, as shown in FIG. **1**. The information is in this case the voice message, which was transmitted over the communications network.

The process of representing information can be analog or digital. In an analog communications network the message that is transmitted is a continuously changing number. In a digital network, numbers that change at discrete, regular intervals, instead of continuously represents the message. The signal is represented by a single number each interval. This number may be converted to a binary form so that the entire message can be represented as a finite number of ones and zeros. Each binary digit in the message is called a bit. These bits are transmitted and interpreted by the receiver as the message. Binary and digital versions of a signal are shown in FIG. **2**.

Data communication networks are a specific type of communication network that transmit digital information, represented as bits or bytes (a group of 8 bits), in an indoor or outdoor, wired or wireless network from a transmitter to a receiver. While conceptually simple, the means of transmitting the data from some point A to some point B are complicated and varied in implementation. Hundreds of protocols, hardware devices, software techniques and programs exist to handle how data is sent correctly and efficiently. The exact performance of a given data communication network is extremely difficult to predict or even measure because of this complexity and additionally because of the performance effects of the time varying nature of data communications networks and the channels they operate in.

Data communication network can be classified as either a circuit switched or a packet switched network. Both network types use channels to transmit information. A channel is a named communications path between users of a communications network. A channel may consist of many different individual hardware devices and is a specific route between a transmitter and a receiver. In a circuit switched network, information is transmitted by way of an exclusively reserved channel. A network channel is reserved for the sole use of a single transmission and bits are sent all at once. An example of this is the transmission of a document using a fax machine. In this case the fax machine converts the image of the document into pixels. Each pixel is a small, dot-sized, rectangular piece of the paper. Each pixel is considered to be either black or white. The data that will be transmitted is a series of bits that represent whether each dot is black or white. When the message (in this case an image of a document) is ready to be sent from one fax machine to another, a telephone circuit is dedicated to the data transfer by placing a telephone call on the plain old telephone system (POTS) communications network. The telephone line is used exclusively by the fax transmission, making it a circuit switched transmission. After establishing a connection, all data is sent from the first fax machine to the second in a single, long stream of bits. The bits in this case are transmitted as different frequency tones on the telephone line. A high pitched toned may represent a "1" while a low pitched tone may represent a "0." The receiving fax receives the bits of the message by translating the series of high and low pitch tones into data bits. The receiving fax machine will then be able to reconstruct a copy of the original document by drawing a black dot at the locations indicated by the data bits.

Packet switched networks are another type of data communication networks in which all data bits are transmitted as many, small chunks of data bits called packets and sent individually from one location to another. A packet is a

self-contained portion of a full message that is made up of a header, data bits, and sometimes footer. The packet contains information in the header and footer that allows the data communications network to properly transmit the packet and to know of which message the data in the packet is a part. The header generally is labeled with an identifier that the network uses to forward the packet to the correct receiver. The header and footer information are often used to reassemble the packet with other packets to reform the original message and to check if errors were made in the transmission of the packet. The receiver can assembles all received packets into the original message by throwing away the header and footer headings and reassembling the data bits from all packets into the original message.

Packet switched networks are classified as connection oriented or connectionless depending on how the packets are transferred. In connection-oriented networks, a network channel is used predefined for each transmission. While this transmission can consist of multiple packets, the route from transmitter to receiver is already established, so that all packets sent on this channel can immediately be sent directly to the receiver. Whereas, in connectionless networks, packets are sent simultaneously on a shared channel in multiple transmissions. In this case, packets require an identifier that gives the address of the receiver. This address is understood by the communications network to allow the packet to be properly sent to the correct receiver. Since each packet can be transmitted separately and thus interleaved in time with packets from other transmissions, it is generally more efficient to use a connectionless transmission method when using shared network resources.

An example of a connectionless, packet-based transmission is a file transfer between two computers on an internet protocol (IP) based, Ethernet network that both computers are attached to. In this case, the file that is to be transmitted is fragmented at the transmitter into appropriate packets and labeled with the IP address, which is the identifier used by the network to forward the packet to the correct receiver. The packets are then sent from the transmitting computer to the receiving computer. The Ethernet network is capable of supporting multiple file transfers from many different computers all using the same network by controlling the flow of packets from each destination in a shared fashion. The receiver then assembles the packets into an exact copy of the original file, completing the transmission.

All data networks utilize some form of communication protocol to regulate the transmission and reception of information. A protocol is the set of rules that all hardware and software on a communication network must follow to allow proper communication of data to take place. Many hundreds of protocols are in active use today in the worldwide exchange of information. Some of these protocols, such as the Transport Control Protocol (TCP) or the User Datagram Protocol (UDP), define the way in which the network is accessed. Other protocols, such as the Internet Protocol (IP) or the File Transfer Protocol (FTP), define how messages and packets are formatted, transmitted, and received.

All data communication networks may be analyzed in some fashion to evaluate the efficiency and performance of the network as well as to confirm the network is functioning properly. In order to evaluate the functionality of these data networks, certain performance criterion is used. These performance criteria include, but are not limited to: throughput, bandwidth, quality of service, bit error rate, packet error rate, frame error rate, dropped packet rate, packet latency, round trip time, propagation delay, transmission delay, processing delay, queuing delay, network capacity, packet jitter, bandwidth delay product and handoff delay time. Each performance criterion specifies a different performance parameter of a data communications network. These criterions are further described below.

A link is a portion of a path followed by a message between a transmitter and a receiver in a data communications network. Network connection often consists of individual devices relaying network packets from the transmitter to the receiver. This means a network connection can consist of several actual transmissions between the original transmitter and the intended receiver. Each individual relay is called a link. Typically a full network connection consists of several links. Performance criteria can be measured for each individual link.

Throughput is a measurement of the amount of data, which can be transmitted between two locations in a data network, not including header, footer or routing information bits. It is generally measured in bits per second (bps) and can be specified for hardware, software, firmware or any combination thereof that make up a connection between transmitter and receiver in a data communication network. Bandwidth is similar to throughput as it is defined for data communication networks. Bandwidth is the raw data rate that may be sustained by a given communications network and is generally slightly higher than throughput. For instance, an Ethernet link may be rated for a 10 Mbps bandwidth but a measurement of an actual file transfer may show that the rate at which data can actually be transferred between two computers using that same link is only a throughput of 6.8 Mbps as is taught in Peterson, L. L. and Davie, B. S., *Computer Networks: A Systems Approach*. San Francisco: Morgan Kaufmann Publishers, 2000.

Quality of service (QoS) is a term that is used to describe networks that allocate a certain amount of bandwidth to a particular network transmitter. Such a network will allow a transmission to request a certain bandwidth. The network will then decide if it can guarantee that bandwidth or not. The result is that network programs have a reliable bandwidth that can more easily be adapted to. When the quality of service of a connection is measured, the bandwidth that the network claims to offer should be compared to the actual bandwidth for different requested bandwidths.

FIG. **3** illustrates the difference between bits, packets, and frames. Various error rates are defined for data communication networks for bits, packets and frames. Bits are the core of packets and frames. The bits are the actual message data that is sent on the communications network. Packets include the data bits and the packet header and packet footer. The packet header and packet footer are added by communications network protocols and are used to ensure the data bits are sent to the right location in the communications network and interpreted correctly by the receiver. The packet header and packet footer are also used to ensure that packets are sent correctly and that errors are detected should they occur. Frames are simply series of bits with a certain pattern or format that allows a receiver to know when one frame begins or ends. A bit error rate is the percentage of bits that reach the receiver incorrectly or do not reach the receiver as compared to the number of bits sent. Packet error rate or dropped packet rate is the percentage of packets that reach the receiver incorrectly or do not reach the receiver as compared to the number of packets sent. A frame error rate is the percentage of frames that reach the receiver incorrectly or do not reach the receiver as compared to the number of packets sent.

Several terms are used to quantify the delay times of certain network events and may be expressed in time units

of seconds. Packet latency is the time required to send a packet from transmitter to receiver, while Round Trip Time (RTT) is the time required for a packet to be sent from transmitter to receiver and for some sort of acknowledgement to be returned from the receiver to the original transmitter. Propagation delay, transmission delay, processing delay, and queuing delay describe the time required for different portions of a packet transmission to occur. The packet latency and round trip time of a network connection is found by summing the propagation delay, transmission delay, processing delay and queuing delay of either a one way or round trip network connection. Propagation delay is the time required for a packet to traverse a physical distance from the transmitter to the receiver. Transmission delay is the time required from when the first bit of a packet arrives for the last bit of the same packet to arrive. Processing delay refers to the time required to subdivide a data message into the individual packets at the transmitter, and to the time required to recreate the full data message from the data packets at the receiver. Queuing delay refers to the time spent waiting for shared resources to be freed from use by other transmissions. These delay times are all useful for evaluating different aspects of a data communications network performance.

Two other network performance criteria are packet jitter and bandwidth delay product. Packet jitter is the variation in the arrival time of packets that are expected to arrive at a regular rate and is typically measured in time units of seconds. A bandwidth delay product is the number of bits that can be sent from a transmitter before the first bit sent actually reached the receiver. The bandwidth delay product is found by multiplying the packet latency of a certain link by the bandwidth of the same link.

Handoffs occur in wireless data networks when a user moves out of range of one access point and into range of another access point. In this situation, the first access point must pass the responsibility of delivering data to the wireless user to the second access point. The handoff time is the amount of time required by an access point to coordinate with another access point to allow a wireless user to connect from one access point to another access point.

Software utilities and hardware devices have been developed to measure the performance statistics of data communication networks throughout the lifetime of data communication networks. Some of the more common and relevant tools are briefly described here.

A large number of command line tools are available to quickly allow a computer user to measure the approximate network performance a connection. Many command line programs are widely used on Windows, UNIX, and Macintosh operating systems and are somewhat useful for diagnostic and troubleshooting work on data networks. Examples of these command line programs include ping and traceroute. Using the ping command line program, it is possible to measure approximate data latency between different data network devices and confirm that a network connection is available between the two devices. Network connections often consist of individual devices relaying network packets from the transmitter to the receiver. This means a network connection can consist of several actual transmissions between the original transmitter and the intended receiver. Each individual relay is called a link. Typically a full network connection consists of several links. Thus, using traceroute, a probable path from relaying device to relaying device between the transmitter and the receiver can be determined so that the exact links used by the network transmissions are known. Additionally, using traceroute, the time required to traverse each individual link can be measured, and individual links that may not be functioning properly can be identified.

Various command line tools that are not included with operating systems have also been developed for somewhat more accurate, though still approximate, network measurement tasks. Some examples of these tools include ttcp, and tcpdump. ttcp stands for Test TCP http://www.pcausa.com/Utilities/pcattcp.htm and is a free utility originally written for the BSD Linux operating system, but is now available for other UNIX operating systems as well as Microsoft Windows. ttcp is a basic point-to-point throughput measurement program that allows the user to control buffer sizes, various low level TCP or UDP options and control the exact data that is sent.

tcpdump is a simple utility from the class of tools called packet sniffers. Packet sniffers allow a network administrator to view the content, including header and footer information, of actual packets on a network. tcpdump allows a user to view (or "sniff") packets that are received by a host (though not necessarily intended for that host) and display all headers that match a certain user configurable pattern. tcpdump is a useful tool for troubleshooting network connections because it allows the user a direct view of the exact network traffic.

Pathchar is a UNIX command line utility which is capable of measuring the throughput between each network relay device (e.g. a router, hub or switch) in a data communications network by varying the size of the test packets that it transmits and measuring the latency of that packet transmission to various network points. The tool functions very similarly to traceroute but adds the ability to measure throughput (albeit indirectly), not just latency. Pathchar is only limited by the network hardware in the links it measures. The program needs a hub, switch or computer to transmit an acknowledgement to the test packets. This means that hidden links that do not transmit acknowledgements such as Ethernet bridges can not be measured individually by pathchar.

Several companies produce network measurement, monitoring, tracking and forecasting utilities. Some of the commonly used utilities are discussed below. The tools selected are illustrative of the state of the art of network performance measurement and asset tracking.

netViz, made by netViz Corporation, is a visual database program that allows a network administrator to track network equipment in terms of its physical location and in terms of its logical layout. This program allows the user to input the settings, locations, and configurations of the network and track the assets in your network. The tool is capable of storing this data in a two dimensional geographic map or floor plan of a building, but can not track devices in a three dimensional manner. The tool, also, does not provide network testing, measurement or monitoring features, nor does it support communication prediction or performance visualization capabilities for data communication networks. It is simply a database for accurate and useful tracking of assets.

NetIQ Corporation (was Ganymede Software, Inc.) makes a network monitoring and forecasting tool called Chariot. Chariot is able to measure throughput and many other network statistics for all popular network types, operating systems and protocols available today. The program uses a server and several small agent programs to collect data. The server checks each agent, installed on user's computers throughout the network, at regular intervals and uses them to measure network characteristics while storing

the results on the server. These agents can measure the network connection to the server or to one another and are capable of simulating the traffic patterns of any network program and any desired usage pattern of one or more hypothetical users. The program is also capable of using the measured data to forecast expected network traffic and conditions.

Visonael Corporation (was NetSuite Development Corporation) makes several network tracking and measurement products, including NetSuite Audit, Design and Advisor. These software products are capable of automatically detecting the network equipment in use. This information as well as manually entered information can then be placed in a physical or logical diagram of the network. Visonael also offers a product to verify that networks have been configured properly and can make recommendations for configuration changes and upgrades to your network. The software products are unable to predict or measure the performance in a site-specific manner and are not capable of predicting the performance of wireless based data communication networks.

SAFCO Technologies, Inc. (now a part of Agilent Technologies) has recently created several wireless data measurement and prediction products. SAFCO makes a product called DataPrint, which is used to measure various data performance parameters of mobile telephone data networks. Their WIZARDS product also supports analysis of the effects of wireless data transmission on the overall capacity and Quality of Service for a wireless telephone network.

Wireless Valley Communications, Inc. has created a new concept called SitePlanner, which is capable of measuring and tracking the site-specific network performance of a data communications network in a physically accurate three-dimensional model of an environment. SitePlanner uses a software module called LANFielder to measure throughput, packet latency and packet error rates for any wired or wireless network connection in any Internet Protocol (IP) data communications network. Additionally, SitePlanner allows a full network to be modeled in a physically accurate manner so that precise measurements and performance predictions can be made in a site specific way. SitePlanner also allows a logical layout of a network to be stored simultaneously with a physical layout. The tool also stores both a logical interconnection and a site-specific model of any communications network using a Bill of Materials format.

In addition to network measurement and asset management tools, a good deal of research has taken place in the field of wireless data communication network performance. The research described below represent the work, which pertains to the field of this invention.

Xylomenos and Polyzos have explored the performance of UDP and TCP packets sent over several fixed, IEEE 802.11 wireless LAN network connections in Xylomenos, G., Polyzos, G. C. "TCP and UDP Performance over a Wireless LAN" *Proceedings of IEEE INFOCOM,* 1999. The research has focused on throughput limitations caused by software implementation issues and operating system shortcomings. The researchers used their own modified version of the command line utilities ttcp, tcpdump and nstat under Linux to perform UDP and TCP throughput tests. All measurements were taken between three fixed locations and focused on varying the wireless LAN card types (PCMCIA or ISA) and the end-user computer hardware (i.e. Pentium 150 with 48 MB of RAM vs a Pentium 200 MMX with 64 MB of RAM). The conclusions the researchers make are recommendations for changes in the implementation of

network protocols and linux operating system enhancements. The measurements did not consider the effects of different physical locations or the effect of variations in the wireless communications channel on the network throughput.

Maeda, Takaya and Kuwabara have published a measurement of wireless LAN performance and the validity of a Ray tracing technique to predict the performance of a wireless LAN network (Maeda, Y., Takaya, K., and Kuwabara, N., "Experimental Investigation of Propagation Characteristics of 2.4 GHz ISM-Band Wireless LAN in Various Indoor Environments," *IEICE Transactions in Communications, Vol. E*82-B, No. 10 Oct. 1999). The measurements were tracked in a small, highly radio frequency (RF) controlled environment and indicated that the wireless LAN throughput and BER were correlated to the delay spread of the wireless channel. The researchers have not however presented any way to actually predict a bit error rate or throughput from the predicted delay spread profile output by a ray tracing technique.

Duchamp and Reynolds have presented IEEE 802.11 wireless LAN, packet throughput measurement results for varying distances in Duchamp, D., and Reynolds, N. F., "Measured Performance of a Wireless LAN," *Local Computer Networks,* 1992. *Proceedings., 17th Conference on,* 1992. These measurements were performed in a single hallway. Thus, these measurements, too, suffer from failing to measure a representative environment. The researches did not present a model to predict their results nor did they attempt to validate any sort of computer prediction technique.

Bing has also presented measured results of the performance of IEEE 802.11 Wireless LAN in "Measured Performance of the IEEE 802.11 Wireless LAN," *Local Computer Networks,* 1999. *LCN '99. Conference on,* 1999. Bing presents delay and throughput measurements as well as theoretically based throughput and delay time tabulations for various wireless LAN configurations. The results are given as optimal results, however. All measurements were performed in such a way that the wireless channel had the least possible effect on the overall throughput and delay times. Therefore, the results presented are an upper bound on best possible results and do not extend into a site-specific wireless LAN performance prediction technique.

Hope and Linge have used measurements to calculate the needed parameters for predicting the coverage area of a Wireless LAN network in an outdoor environment by using the Okumura model. The researchers have made outdoor measurements with standard IEEE 802.11 wireless LAN modems to calculate the needed parameters of the Okumura model and have presented these results in Hope, M. and Linge, N., "Determining the Propagation Range of IEEE 802.11 Radio LAN's for Outdoor Applications," *Local Computer Networks,* 1999. *LCN '99. Conference on,* 1999. Using these results, The coverage area outdoors could be calculated. However, the results do not allow the user to predict the performance in terms of throughput or latency of a wireless LAN.

Several patents related to, and which allow, the present invention are listed below:

U.S. Pat. No. 5,491,644 entitled "Cell Engineering Tool and Methods" filed by L. W. Pickering et al;

U.S. Pat. No. 5,561,841 entitled "Method and Apparatus for Planning a Cellular Radio Network by Creating a Model on a Digital Map Adding Properties and Optimizing Parameters, Based on Statistical Simulation Results" filed by O. Markus;

U.S. Pat. No. 5,794,128 entitled "Apparatus and Processes for Realistic Simulation of Wireless Information Transport Systems" filed by K. H. Brockel et al;

U.S. Pat. No. 5,949,988 entitled "Prediction System for RF Power Distribution" filed by F. Feisullin et al;

U.S. Pat. No. 5,987,328 entitled "Method and Device for Placement of Transmitters in Wireless Networks" filed by A. Ephremides and D. Stamatelos;

U.S. Pat. No. 5,598,532 entitled "Method and Apparatus for Optimizing Computer Networks" filed by M. Liron et al.

U.S. Pat. No. 5,953,669 entitled "Method and Apparatus for Predicting Signal Characteristics in a Wireless Communication System" filed by G. Stratis et al.

U.S. Pat. No. 6,061,722 entitled "Assessing Network Performance without Interference with Normal Network Operations" filed by W. J. Lipa et al.

U.S. Pat. No. 5,831,610 entitled "Designing Networks" filed by D. L. Tonelli et al.

U.S. Pat. No. 5,821,937 entitled "Computer Method for Updating a Network Design" filed by Tonelli et al.

U.S. Pat. No. 5,878,328 entitled "Method and Apparatus for Wireless Communication System Organization" filed by K. K. Chawla et al.

An existing product, SitePlanner, described in patent application Ser. Nos. 09/352,678, 09/221,985, 09/318,842, 09/318,841, 09/318,840, and other inventions cited previously, are useful for designing, measuring and optimizing communication networks because the products can predict radio frequency effects directly relevant to any communication network for any physical location. That is, using information about the physical layout of any communications network and the configuration of its hardware, prior art can provide a visual display of the expected received signal strength intensity (RSSI), signal to noise ratio (SNR), relative received power intensity, best server, and equal power location, as well as other useful parameters for voice and data networks, for any modeled physical location. These statistics can be predicted for the forward link (from a transmitter to a receiver), or for the reverse link (replies from the original receiver to an original transmitter) directions for wireless networks. The site-specific nature of these predictions translates directly into quick and useful visualizations of the quality of a communication network. However, the prior art does not consider methods for properly modeling (e.g. predicting) the complexities that go into determining the values for actual network operating performance parameters that are simultaneously affected by multipath propagation, multiple interfering data transmissions from multiple sources, signaling protocols, equalization methods, and the like. Predicting bit error rates, data throughput, delay, and quality of service metrics in a 3-D physical model of an actual site-specific environment is a very difficult task, and one which has not been solved heretofore, since different modem vendors have different and often-times proprietary methods for mitigating or dealing with multipath, multiple access interference, protocol type, packet size, and noise. That is, the state of the art shows how to measure and display and make predictions for basic communication metrics but does not provide specific prediction algorithms for a wide range of important data network performance parameters in a reliable, site-specific manner. Simply put, a wireless network performance prediction engine, which is able to consider an accurately modeled 3-D physical environment, and which exploits knowledge of specific component layouts, is not found in the prior art and is not obvious due to the complex nature of having to account for all possible physical, electrical, and logical factors for all components in a

network, as well as the factors within the channel of a wired or wireless network, that lead to actual network performance.

Prior published papers in the area of communications networks do not demonstrate the ability of any invention to accurately predict three dimensional, site-specific network performance criteria. The paper mentioned earlier by Maeda, Y., Takaya, K., and Kuwabara, N., "Experimental Investigation of Propagation Characteristics of 2.4 GHz ISM-Band Wireless LAN in Various Indoor Environments," *IEICE Transactions in Communications*, Vol. E82-B, No. 10 Oct. 1999 has demonstrated the ability to predict the delay spread of a wireless channel and that the prediction correlates well with throughput, but the described method is not actually able to predict throughput or any other network performance criteria. While some prior art has demonstrated the ability to track network assets in a two dimensional manner with some physical accuracy, these products have not contemplated the ability to predict future network performance for similar or different physical environments (e.g. installations). Many products allow the measurement of network performance criteria, but no prior art has contemplated a 3-D representation of the physical environment with the physical installed base of components, for the purpose of predicting network performance parameters. Furthermore, no tool or invention exists that can directly measure, track the assets of, predict the network performance criteria of, and visualize the network performance criteria of a data communications network in a three-dimensional site-specific manner.

Furthermore, none of the prior art has considered an invention that can perform precise, site-specific, three dimensional performance prediction of complicated network parameters using a priori measurements from an existing network, or by using the site-specific layout details of particular components within a data communications network. Furthermore, none of the prior art has autonomously measured site-specific network performance parameters from an actual network system or subsystem using a system of agents, and then applying the specific 3-D locations and measured results of those measurement agents to create a 3-D prediction model for future network performance in the same, similar, or different physical environments. Furthermore, none of the prior art has developed a hierarchical system of measurement and prediction engines, that have the ability to measure network performance parameters in the field and have the ability to produce a predictive engine for network performance parameters that can be shared with remote prediction engines, for the purpose of measuring and predicting network performance in a 3-D site-specific manner.

The present invention extends the prior art in a non-obvious way to provide wireless and wired network performance prediction, visualization and measurement for important data communications-specific performance criteria, also called performance parameters, such as throughput, bandwidth, quality of service, bit error rate, packet error rate, frame error rate, dropped packet rate, packet latency, round trip time, propagation delay, transmission delay, processing delay, queuing delay, network capacity, packet jitter, bandwidth delay product and handoff delay time in a site-specific, three dimensionally accurate manner. The invention contemplated here allows novel distributed measurement techniques for the above performance parameters. Furthermore, prediction methods for the above performance parameters are created, which use network measurements or applied values derived from other means, and which also use the

radio frequency environment, the 3-D physical network layout, the channel propagation characteristics of a site-specific environment, and the specific physical layout of components, for the computation of predicted performance parameter values.

SUMMARY OF THE INVENTION

The present invention is capable of predicting, measuring, and optimizing the performance of a data communications network. The invention is capable of representing a detailed layout of a fully deployed or contemplated communications network within a physically accurate computer representation or model of a three dimensional environment. This allows the invention to store measurements and determine performance predictions within a site-specific representation of the physical environment, while using specific information about the network entities, components, subsystems, and systems used to create the actual or contemplated network. Measurement agents, with known or assigned 3-D position locations, are used to measure in-situ performance parameters that are transmitted to a server processor. The server processor has an accurate 3-D model of the environment, and is able to process the measured data, and is also able to provide predictive models using site-specific information that may be independent of or may make use of measured data. The server process is able to communicate with other server processors in a hierarchical manner, such that data fusion from many remote or collocated networks may be assembled and used for display and cataloging of measurements that may or may not be used for creation of predictive performance models. Alternatively, each server processor is able to compute predictive performance models without the use of measured data, by simply considering the site-specific layout of physical components, as well as the specific delay times, transit times, propagation effects, and multipath and noise factors within the physical network.

The invention can predict throughput, bandwidth, quality of service, bit error rate, packet error rate, frame error rate, dropped packet rate, packet latency, round trip time, propagation delay, transmission delay, processing delay, queuing delay, network capacity, packet jitter, bandwidth delay product and handoff delay time in a site-specific, three dimensional model of any environment. The invention can measure and predict all of the above performance criteria and store the results in the physically accurate three-dimensional model of a data communications network and the environment in which it is installed. Further, the invention can display the measured and predicted performance criteria for any data communications network in the three dimensions, site-specific model of the environment. These capabilities provide a powerful design environment for wired and wireless networks, which allows one skilled in the art to quickly and easily design, measure, predict, optimize and visualize data network communication performance criteria in a three dimensional, site-specific manner using methods never before contemplated.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1**: Example transmission of data over a communications network

FIG. **2**: Creation of a digital signal from an analog signal

FIG. **3**: Illustration of the difference between bits, packets and frames.

FIG. **4**: Illustration of the data displayed in each node of the Tree View of a data communications network.

FIG. **5**: Method for creating a 3-D site-specific model of the environment

FIG. **6**: Method for optimizing a data communications network using predictions

FIG. **7**: Method for optimizing a data communications network using measurements

FIG. **8**: Method for optimizing a data communications network using predictions and measurements.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

The present invention contemplates the abilities to design, measure, predict and optimize the performance of a data communication networks. The invention uses an accurate computer generated three-dimensional model of a communications network stored in a computer database environment. The invention allows the user to place the network cables, hubs, routers, switches, bridges, wireless access points, amplifiers, splitters, antennas (point, omnidirectional, directional, leaky feeder, distributed, array, etc.) transceivers, terminators and other communications and computer networking equipment in their actual modeled physical locations. The present invention uses this highly accurate model of the physical layout of infrastructure to allow a user to visualize, predict and optimize the performance of any communication network in any 3-D site specifically modeled physical location.

The present embodiment of the invention is capable of modeling the site-specific communications network hardware from both a logical connection and a physical location perspective. The invention uses well-known hierarchical, logical connection concepts (sometimes called topological layout) suited for data communications networks in combination with a physically accurate, site-specific model of the data communications network. Previous inventions focus on only the topological, or relational, layout of network components with one another. This invention uses specific 3-D modeling and, therefore, allows highly accurate asset management and facilities tracking of actual installed equipment while simultaneously providing for network performance prediction, measurement, and design capabilities that exploit the exact physical dimensioning of the network. In addition, the invention simultaneously stores an inventory of important network-specific and equipment-specific characterizations of all objects used in the network, such as vendor, model number, network hardware type, operating system version, firmware and software type and version. The hierarchical, tree based model of the network is termed the Layout View. The physically accurate, site-specific model of the network is termed the Site View, whereby the attributes of each device can be displayed, stored or printed by selecting a particular item or node within the 3-D environmental model. Further, network hardware and software components can be interactively replaced, removed, reconfigured or moved to a new location in real-time using either the Layout View or the Site View. Each of these ways of tracking and designing a network in a 3-D site specific model of the environment with accurate dimensioning of true spatial position are further described below and are used to create a Bill of Materials for the modeled data communications network, whereby a preferred embodiment is described in co-pending patent application "Method and system for designing or deploying a communications network which considers component attributes," filed on Aug. 4, 2000.

An example of some of the information contained in the Layout View, hierarchical layout of a data communications network is shown in FIG. **4**. In the figure, a tree structure is used to display all hardware in the network. Each node in the tree contains information which is used to track the true physical location, logical layout and electrical, optical and electromagnetic connections for the data communications network hardware as well as any version numbers and settings of software or firmware running on that network equipment and the known performance parameters of that equipment, including the device throughput, bandwidth, quality of service, bit error rate, packet error rate, frame error rate, dropped packet rate, packet latency, round trip time, propagation delay, transmission delay, processing delay, queuing delay, network capacity, packet jitter, bandwidth delay product and handoff delay time.

The Site View of the invention has a physically accurate, three-dimensional modeling capability to display all network devices in a site-specific model of the environment that the network is located in. That is, the preferred embodiment of the invention allows each modeled hardware and software device to be placed in a three-dimensionally accurate manner and to track attributes of that device relevant to data communications networks. These key attributes include such items as the hardware type, hardware configuration, software type, software configuration, operating system version, as well as upper, lower and "typical" specifications for each component. These specifications may include important device or network subsystem operating parameters, such as throughput, bandwidth, quality of service, bit error rate, packet error rate, frame error rate, dropped packet rate, packet latency, round trip time, propagation delay, transmission delay, processing delay, queuing delay, network capacity, packet jitter, bandwidth delay product and handoff delay time. As described below, the Site View supercedes prior art described in previous co-pending patent applications by Wireless Valley Communications, Inc by hereby considering the difficulties and solving data network prediction, design and optimization problems for more complicated data communication networks. Specifically, this new invention considers physical, site-specific modeling techniques and performance prediction methods and design methods for data network systems, both wired and wireless, which have performance characteristics that are based on much more complicated physical factors than just radio signal strength, interference, or multipath alone. In particular, for data communication networks, many additional factors, which relate to particular network equipment or modem designs, such as packet size, equalizer deployment, modulation methodology, source and error coding methods, packet protocols, as well as the number of co-channel network users, the type of persistency used for packet retransmission, or the multipath propagation effects in a wireless system, provide additional factors that must be considered in the design of a communication network that is designed for data traffic as opposed to simply voice traffic.

One difficulty that today's network designer or network system administrator faces is that most networking equipment uses proprietary, non-public methods for implementing various network devices, and these methods vary by specific vendor. Thus, it is difficult to form reliable prediction models by just using basic physical propagation models in a wireless network, for example. As data transmission technologies such as Bluetooth, DSL, Voice over IP, and future packet-based cellular radio network architectures proliferate, the ability to predict and measure specific network performance parameters will become increasingly important, and the ability to properly incorporate measurements into 3-D prediction models for performance parameters will be important for proper network deployment.

This invention considers attributes relevant to packet-switched data communication networks, which require more extensive and non-obvious modeling when compared to traditional cell phone or telephone voice communication systems that are circuit switched and use a dedicated single user (or bounded number of users) per assigned operating channel. Data communication networks have performance criteria that are specific to packet-based systems and that are not useful to all types of communication networks contemplated previously. For this reason, the preferred embodiment of the invention can additionally predict the throughput, bandwidth, quality of service, bit error rate, packet error rate, frame error rate, dropped packet rate, packet latency, round trip time, propagation delay, transmission delay, processing delay, queuing delay, network capacity, packet jitter, bandwidth delay product and handoff delay time, based on the specific physical and spatial location of each network component, as well as the physical, electrical, and logical attributes of the specific components. The performance prediction methods take into account all devices and network equipment, including the physical locations within the 3-D modeled environment, using the constructed Bill of Materials of the network within the 3-D modeled environment, and is capable of performance predictions for any desired location in the modeled network and environment, where a location may be within a room, at a particular location in a room, within a building, or in an outdoor region of varying granularity, depending on the requirements of the user.

Prediction of throughput, bandwidth, quality of service, bit error rate, packet error rate, frame error rate, dropped packet rate, packet latency, round trip time, propagation delay, transmission delay, processing delay, queuing delay, network capacity, packet jitter, bandwidth delay product and handoff delay time and other performance parameters may be carried out by predicting the performance for all wired network components separately from the performance of wireless components, and then combining the results to get the net network performance. To predict the performance of a wired communication link, it is important to combine the known effects of each piece of wired equipment for the specific network settings, also known as operating or performance parameters, such as protocol type, data type, packet size, and traffic usage characteristics, firmware type, operating system type, typical network performance characteristics, and typical, average, peak, and minimum traffic load on the network. For wireless network components, additional factors concerning propagation, signal strength, interference, and noise must be considered.

The preferred embodiment of the invention allows data communication networks to be accurately characterized for performance prediction in a number of novel ways.

First, performance prediction may be based on field measurements from an actual network, where prediction models are formed from some fit to measured data (an empirically-based model). These field measurements may be made manually, or autonomously, using data collectors, or agents, that continually measure and update the specific network performance metrics that are observed within the physical environment. These data collectors are able to measure, or are assigned, specific 3-D position locations within the physical environment, such position locations corresponding to known positions in the computer model which is used to model the physical environment of the

network, and which are known or which are transmitted to a measurement server. The data collectors may be individuals who manually or automatically record or collect observed network performance such as one or more of the aforementioned performance parameters, or the measurement agents may be software or hardware or firmware applications that run on top of network applications for the purpose of routinely measuring for one of more of the numerous network performance parameters listed previously. The agents may be fixed, or may be portable, and may have position location devices, such as GPS or inertial navigation, or an internal map which is activated by a user, so that the position location of the measurement is sent to a server processor. The agents are presumed to have two-way communication with a server processor that may be collocated or remotely located. Measurements from one or more data collectors are routinely or periodically collected and then transmitted, either by wireless or wired means, or by real-time or stored means, to a server processor which is either collocated, or remotely located, from one or more of the measurement agents. For example, the measurements may be recorded by autonomous agents and then transmitted over a fixed network to a processor that integrates all measurements and computes statistics for observation. The measurement sources have known positions in 3-D, or may not be known and used to form a gross estimate of observed network performance. The collected measurements may be sent in real time, stored and forwarded, or sent as file transfers via many means, such as via email, over the world wide web, via wireless, wired or optical links, or in a storage device. This "in-situ" measurement data is passed, with the 3-D position location when available, to the server, which catalogues and processes the specific measurement information. Using the measurement information from the data collectors, the server is able to provide a predictive model by using knowledge of the physical 3-D environment, and by fusing the many collected inputs into a simplified model of performance that is related to the 3-D physical representation of the world.

In the preferred embodiment of the invention, the server stores and processes the physical location of all measurement devices (where available) as well as all network components and their electrical, logical and technical configuration, while also considering cost and maintenance issues associated with each network component. Using the preferred embodiment, a data communications network can be designed, deployed, tested, predicted, measured, optimized and maintained by collecting the measured data from one or more agents, and processing them at the server to determine a proper prediction engine that allows future network layout with a desired outcome prior to installation. The server engine is able to display the measured results, in a site-specific manner from each measurement agent (that has site-specific information) so that predictions may be compared to measurements on a visual display of a computer or in a stored means (such as an ASCII file comparing predicted versus measured performance parameters).

It is important to note that each measurement agent may be a server, capable of fusing measurement data with the site-specific 3-D layout of the network components and the physical environment. Therefore, each measurement agent may serve as a centralized processor, as well, so that many different physical locations of a particular network may be measured and predicted for performance. Servers may then be collocated or remotely located from the measurement agents, which collect, display, store and use the measurements to form predictive models. In the case of a remote server that receives measurement data from measurement agents, it is possible to remotely monitor, and then predict, the performance of a network that is physically very far from the particular server processor.

The measurement agents may be further controlled or configured by the server processor, so that the agents may be tuned or instructed to perform different types of measurements, such as different packet transmission rates, observation intervals, averaging intervals, protocol types, or other sensible changes which those skilled in the are would conceive for proper network optimization.

A second method for predicting the performance of network parameters is through the use of analytical or simulation methods. These analytical and simulation methods are well known, and relate the physical and electrical characteristics of the network channel to the physical and electrical characteristics of the various network components. Through simulation or analysis, it is possible to determine approximations or bounds on the typical values that one would expect in an actual network configuration of specific components. The present embodiment of the invention allows a user to enter the results of such calculations, so that they are applied as inputs to the prediction model. Therefore, a user of the invention may simply enter "blind" values, based on known methods, as a first guess approach to forming a prediction model of network performance. These first-guess values may then be iterated by the invention, based on feedback from the site-specific measurements of the actual network.

A measured set of data for a typical operating environment with multiple transmitters in a wireless or wired network, are recorded, stored and displayed by the invention, as taught in the previous description about the measurement agents and server processors. Then, some form of best-fit algorithm (minimum mean square, median filter, etc.) may be applied to the predictive models provided in the equations taught below to provide a table look-up for determining proper performance values (e.g. proper values for constants or functions in the performance parameter equations listed below) for a particular site-specific network design. This table look up method allows measured data to be translated into values that may then be used to drive predicted data for all subsequent predictions conducted within the same site-specific 3-D environment in which measurements were made. Alternatively, best guess performance metric values, or best guesses for the functions or constants in the equations listed below, may be fed into the invention, either manually or automatically through a storage means or via a wireless or wired means from a remote or collocated location, for a specific 3-D modeled network environment, wherein the predicted performance at any space or location with the 3-D environment is based on the first, best guess, predictive models. As explained subsequently, these initial best guess, or "blind" models may be based on simulation, analysis, or some combination thereof. The empirically-based predictive models and the initial best guess predictive models may be used in subsequent environments, different from the environment for which measurements or best guesses were made, and the invention allows a catalogue of models to be used easily by the user for subsequent network prediction or design. Measurements of actual network performance may then be overlaid and displayed and stored simultaneously with the network prediction parameters, for rapid comparison. Furthermore, optimization routines compute the best values for minimum error for new predictive models that match the measured network performance within the environment. Thus, the

invention allows the user to relate empirically-derived predicted performance parameters or initially guessed network performance parameters within a 3-D site specific configuration of the actual installed or contemplated network, using specific information and physical locations about the network devices and by using the models for wired networks and wireless propagation, multipath, and noise. The model techniques for this invention fuse the many factors that impact network performance into simpler models that support prediction and comparison of measured versus predicted network performance for radio/wireless and wired networks. Thus, performance prediction can be ascertained and compared to measured network performance for use in ongoing network deployment.

Furthermore, by comparing measured network performance metrics to predicted metrics, the invention allows new field measurements to update the previous prediction models in a convenient method, which provides a catalogue of models that is stored and displayed to the user either locally or remotely. Alternatively, using the hierarchy of servers, it is possible to use remotely located servers which compute, transmit, or receive such measurements and predictive models for the remote use, display, measurement and storage of model parameters and results. This is particularly convenient for network administrators who wish to monitor the performance and design of networks that are physically distant from the network of interest.

Measurements of a particular device for desired performance criteria is accomplished either by using the measurement software module available in the preferred invention or by importing a log file from another software or hardware measurement tool. The measurement module within the preferred invention allows the measurement of the performance of any specific portion of a communications network using two or more software programs which are installed and run on either sides of a device or devices. These software programs are called agents. By sending test transmissions between two agents across a specific network connection the preferred invention can measure any particular performance criterion. The results of these measurements are stored for a particular portion of the network.

The preferred embodiment of the invention can also import the logfiles of other measurement programs such as traceroute to measure specific links. This functionality allows site-specific measurements made by external programs to be stored site-specifically. This is accomplished by a two-pass method described in patent 09/221,985, "System for Creating a computer model and measurement database of a wireless communication network" by T. Rappaport and R. Skidmore, filed Dec. 29, 1998. To import a logfile a user simply clicks a point in the model of the environment for each data point to assign a location for each point in the logfile.

In performing network performance measurements, especially for wireless data networks, it is important to know the difference in performance for transmission and reception. This is why the preferred invention can measure the transmission and reception components of the average network statistics. To measure the transmission direction, the size of test packets is varied. By changing the size of the packet sent and the size of the packet returned, the transmission and reception statistics can be separated. This allows a network designer to identify problems in transmission that might otherwise be masked by apparently good reception.

Network performance measurements are not useful if the measurements do not mimic the actual data traffic that a network carries. For this reason, the preferred embodiment of the invention is able to mimic the traffic patterns, network protocols and packet characteristics of actual data. Thus, if web browsing performance is being measured, the invention sends small packets from an access terminal to a web server and returns large packets from that server that are typical of text, image and web script file formats. By measuring the performance of such packets, the invention accumulates accurate network statistics for expected web browsing performance.

The measurements of specific traffic types may also be applied to the use of broadcast or multicast packet performance scenarios. The preferred embodiment of the invention is able to measure performance of multiple transmitters or multiple receivers or both of the same packet information. The performance of this type of transmission are different than point to point measurement because shared resources are used more efficiently in broadcast and multicast scenarios. Thus, the ability of the invention to measure network performance statistics for the overall success of the broadcast or multicast transmission and for each individual transmitter and receiver is quite powerful. This ability allows network designers to better choose which transmitters of multicasts might be redundant or which broadcast transmissions are insufficient to reach all the desired receivers.

In some data communications network, the performance of specific pieces of equipment, such as Ethernet Bridges or even a single cable, is hard to measure because it is transparent to the network layer of a data communications network. For this reason, the ability of the invention to determine the performance of a single device through extrapolation is quite useful. The preferred embodiment of the invention is able to use known performance data for specific pieces of network equipment and extrapolate the contribution of other devices in the network. Measuring and extrapolating enough individual hardware and software links can identify the performance of all network devices. The accuracy and reliability of this procedure heavily depends on an accurate and site-specific model of the data communications network, which the invention possesses.

Extending the extrapolation concept of performance evaluation to the software and hardware components of network equipment demonstrates a further capability of the preferred embodiment of the invention. The invention is able to distinguish in some cases between the performance limits due to software and those due to hardware. For example, in a situation where the transmitter and receiver are the same computer, no hardware is actually involved in the transmission. By measuring network statistics in this situation, one can quantify the performance of just the computer software. By comparing the situation where the transmitter and send are the same to a situation where the transmitter and receiver are different computers the performance of just the computer hardware can be identified. Since the performance of the software in either case will be quite similar, the performance of just the hardware in a connection between two computers can be extrapolated by assuming the software will perform similarly in either case.

Extrapolating the performance of individual network components from measured performance metrics can be time consuming. For this reason, the preferred embodiment of the invention is able to read in data results from a plethora of measurement tools, system utilities and network logfiles to a single internal format. The invention is capable of reading in the output of command line utilities such as ping or ttcp, the logfiles generated by routers and switches such as tcpdump, or even the logfiles of other commercial measurement programs, and these measurement results are

stored for use in the predictive engine. The combination of these imported files to a single internal format allows the invention to combine many different measurements and activity logs into a single set of network statistics. This process means the invention requires fewer active measurement campaigns and more diverse and accurate data for better and more accurate network performance modeling.

Accurate, reliable representations of a data communication network require a large number of measured data points. Hence, the preferred embodiment of the invention collects a large amount of data quickly and easily using various methods as described above. The invention does this by providing remote data collection agents, which can be installed on data access terminals or embedded in hardware, software, or firmware within an actual device in the network. The remote data collection agents respond to a server program (the processing server) that controls the measurements made by the remote agent. That is, the remote agent can be directed to make a measurement to or from any other remote agent or processing server using any desired protocol, traffic type, network setting, or configuration. This process does not require any input from a human user at the remote agent's physical location. The agents simply records the data when asked with the correct settings and reports the results back to a server which stores data from all remote agents and other measurement tools. The server can generate a variety of detailed reports and use the data to make predictions about expected network performance in future. Servers can also function as agents. In this manner, servers can be organized in a hierarchy or a distributed fashion. This allows servers to report measurements to one another and make measurements using other agents or servers. A network designer at a server can then use all collected and reported data to identify problem areas such as fairness or poor distribution of broadcast data, or problem times, such as increased network activity at lunch time with a data communications network.

In order to improve the value of measurement data collected, the preferred embodiment of the invention identifies the exact (if possible) or approximate location of a remote agent. As discussed earlier, remote agents in this case can either be controlled by a user at that physical location, or controlled remotely by a server. In the preferred embodiment of the invention, the agent uses information about the network layout to identify an approximate location. Determining the nearest piece of network equipment and associating the approximate location with the precisely known location of that network equipment accomplishes this. This approximate location can be further refined using dead reckoning, clicking on a location in a map, or using the global positioning system, laser range finders or some other positioning device known now or in the future.

The preferred embodiment of the invention is not only capable of accounting for the effects of different hardware, firmware, software and configuration settings, but it can also predict the effects of just the hardware and firmware, just the software, or of a single configuration setting. The ability of the invention to measure and thus adjust empirically-derived predictions for these effects allows the optimization of the data communications network. By predicting the effects of changing any detailed aspect of the data communications network, a user can immediately visualize the effect of a new component or a setting change. This ability allows a user skilled in the art to design an optimal data communications network by continually making changes and observing the prediction changes.

We now focus on the details for predicting values for network performance parameters based on knowledge of the 3-D site-specific environment as well as the specific components used in the network design.

The throughput and bandwidth of a network are calculated by the invention as functions of any or all of the following operational parameters which impact performance: distance between transmitter and receiver, physical environment specification, packet sizes, error and source coding schemes, packet overhead, modulation techniques, environment, interference, signal strength, number of users, and for wireless networks, the antenna pattern and type, multipath delay, number of multipath components, angle of arrival of multipath components, radio frequency bandwidth, protocol, coding scheme, and 3-D location. In order to predict the bandwidth and throughput of a network connection, the appropriate functions and constants may be calculated from the listed parameters and then predicted for each location and time desired.

For a wired network, throughput (T) or bandwidth (BW) may be derived from a vendor's specification sheet of a product or device, or may be measured in a special laboratory setting. Alternatively, T or BW may be calculated through analysis or simulation, or may be measured in the field using a number of known devices. These means may be used to determine the proper value for T or BW in a network prediction enging such as contemplated here. A formula for predicting the throughput and bandwidth for a wireless data communications channel is shown in equation 1.

$$T \text{ or } BW = C_1[Ad + Bd^2 + C] + C_2[D(RSSI) + E(RSSI)^2 + F) + C_3\sum_{i=1}^{M}(G_iP_i + K_i) \tag{1}$$

where T is throughput, BW is bandwidth, d is the distance between a transmitter and a receiver. RSSI is the received signal strength intensity, which is the power level of the signal at the receiver, either in absolute values or in logarithmic values. A, B, C, C_1, C_2, C_3, D, E, F, K_i, are constants or may represent linear or nonlinear functions of one or more physical or electrical parameters, such as physical environment type, packet size, modulation, modem type, or other parameters that relate the physical, electrical, or logical environment of the network. These constants or functions take on specific functional values depending upon if T or BW is being solved for. The value M may denote a particular number of multipath components from a particular transmitter, as determined by propagation analysis of the channel, or the term may denote a combination of important multipath components from a collection of transmitters, where the term "important" is based on antenna pattern, physical environment distances, and other wireless propagation factors which are well known to one skilled in the art and which are explained below. The values of G_i and P_i represent gains and power levels, respectively, for each of M different signal components, which may represent individual multipath components or gross signal components from one or more radiating sources, and K_i represents a finite number of constants or functions for each value of i. Note that G_i, P_i, and the individual K_i may be in logarithmic (e.g. dB) or absolute values. These constants or functions in the above equation may be dependent on distance (d) between transmitter and receiver where d may be the straight-line or actual reflected/diffracted distance of the main signal path between

the serving transmitter and receiver, 3-D environment, time of observation or observation interval, noise power, packet sizes, coding scheme, number of users, modulation type, interference, and for wireless networks, may include path loss, multipath delay, number of multipath components, angular spread, strength and angle of arrival of received signals, modulation bandwidth, and other physical, electrical and logical settings of particular equipment in the network, and the constants or functions may be calculated analytically, predicted for an initial guess, or solved using best fit methods between measured and predicted performance of actual networks in a site specific environment.

It is important to note that multipath delay, and its effect on network performance prediction and design, may be considered in many ways, as contemplated by this invention and as shown in Equation (1). First, multipath may be considered individually, whereby each multipath component is considered to arrive from each transmitting device, and the methods for modeling multipath are well known and explained in the prior art, and in numerous research works by Rappaport, et. al. from Virginia Tech. Alternatively, gross multipath effects may be modeled as having a worst-case delay (e.g. propagation distance, d) being approximated by the maximum, average, or median length of the specific building or 3-D environment in which the communication network is modeled. Alternatively, spatial considerations may be used by contemplating the antenna patterns of each transmitter or receiver, so that multipath which arrives only in the main beam of each wireless device is considered in the calculation of delay and in network performance in (1). Alternatively, only the strongest one or two or some finite number of transmitters may be considered for multipath propagation delays, whereby only a finite set of transmitters, such as those most closest to the receiver of interest, or those of a certain standard, frequency, or power setting, are considered to radiate multipath energy and produce RSSI values, and from that finite number of transmitters, only the strongest multipath, or the average, maximum, median, or largest few multipath components are considered in computation of delay. Alternatively, if only a finite number of transmitters are considered, methods described above, such as consideration of the physical environment to determine a gross multipath delay from each transmitter, or the use of a particular antenna pattern to determine most important multipath components, may be used to drive the model of multipath and its impact on network performance. Similar approaches may be used to model the received signal strength, RSSI in equation 1.

Note that the constants or functions of equation (1) may be assigned blindly for initial predictions, and then a specific network within the site-specific environment may be measured empirically so that a best-fit (using a minimum mean square error approach or some other well known method) may be used to assign values for the constants or functions in (1). Note that in (1), the distance (d) may be based on true physical distance from the 3-D site specific model of the environment, or may actually represent a relative distance ratio, where the physical distance between two points is referenced to a convenient close-in free space reference distance, as is customary for propagation predictions, and is taught in (Rappaport, "Wireless Communications, Principle & Practice, Prentice-Hall, 1996).

Propagation delay for network data is predicted for wired networks, where components are interconnected by wire (either fiber or metal wire) by dividing the distance traveled by the propagation speed of the electrical, electromagnetic or optical signals in the device, which are used to transmit the data. For instance, data in a fiber optic cable travels at a speed $2*10^8$ meters per second due to dielectric properties of the cable, which affect the photons in a fiber optic cable that are used to transmit the data. Such photons move at the speed of light in glass, which is less than the free space propagation speed. Thus, if the cable is 200 meters long the transmission delay is equal to $1*10^6$ seconds. By using the site-specific method of modeling the complete network within the present invention, it is possible for the user to simultaneously visualize the network as configured in the environment and see a display of delay and predicted or measured performance of delay within the cable within the 3-D environment. Additionally, using a tool tip mouse cursor or some other pointing means, or using a pull down menu, or by simply viewing the display device which the invention is implemented on, various network performance metrics, as well as stored data from the Bill of Materials and parameters of intrest may be visualized or stored.

Predicting the propagation delay for a wireless portion of a data communications network is more difficult than wired networks due to the fact that multiple transmitter sources, such as access points in a Bluetooth network, IEEE 802.11b, or wireless ATM network may be transmitting simultaneously. Furthermore, as mentioned previously, multipath interference can create echoes that may or may not be equalized depending on the specific network equipment used at the wireless receiver or transmitter. However, the same calculation model used for wired networks may be used, with the additional consideration of multipath delay terms, and propagation losses or gains, due to specific multipath components, as shown in Equation (1). This additional consideration of multipath delay is needed to account for the fact that wireless data does not always travel in a straight line, and that physical objects can diffract, reflect, absorb, and scatter radio energy. Thus, to calculate the transmission delay of a wireless link in a data communications network, the distance between the transmitter and the receiver is divided by the propagation speed ($3*10^8$ meters per second) of a wireless communications link and then added to the multipath delay introduced by the indirect paths taken from transmitter to receiver as is shown in equation 2.

$$T_p = \frac{d}{3*10^8 \text{m/s}} + \tau_d \tag{2}$$

Where T_p is the propagation delay in seconds, d is the distance between the transmitter and the receiver in meters, and τ_d is the multipath delay in seconds. Predicting the multipath delay is performed using well-known raytracing techniques or based on angle of arrival, or signal strength values, or by making estimated based on the physical model of the 3-D environment.

Transmission delay is directly calculated from the bandwidth of a connection using the number of bits transmitted. To calculate transmission delay, the number of transmitted bits is divided by the bandwidth. This calculation is identical for wired and wireless channels but must be performed separately for each network device. The formula is illustrated in equation 3.

$$T_t = \frac{\#\text{ of bits}}{BW} \tag{3}$$

Where T_t is the transmission delay time in seconds, # of bits are the number of bits in the transmission or packet and BW is the bandwidth of the network link in bits per seconds.

Processing delay must be calculated for each device separately within a network. Processing delay is the time required for a network device to process, store, and forward the data bits that are applied to a network device. Alternatively, processing delay may be the time required for a source to produce a meaningful data stream once it is instructed to do so. Processing delay is known to be zero for devices that do not perform any processing, such as passive network components like cables, antennas, or splitters. Processing time may depend on the packet size, protocol type, operating system, vendor, firmware, hardware, and software versions or configurations, and the type of device and the current computing load on the device. To predict the processing delay of any device it is necessary use a model that accounts for all of these effects. These models may be measured in the field, measured in a test facility, obtained from vendors, or derived from analysis or simulation.

Queuing delay is only applicable to devices that transmit data from multiple users or multiple connections. The queuing delay of a device is the amount of time a particular packet must wait for other traffic to be transmitted. It is difficult to predict the queuing delay of a particular connection because it depends on the amount of traffic handled by a particular device. For this reason, queuing delays can be predicted using a statistical random variable based on the expected performance of the device and/or the expected traffic load. Alternatively, average, median, best or worst case, or some other linear or nonlinear weighting of queuing delay times as defined by the device specifications, or as measured, simulated, or computed by analysis, may be used to calculate a predicted queuing delay time.

Packet latency, round-trip times and handoff delay times are all based on propagation, transmission, processing, and queuing delay times. To accurately predict packet latency and round trip time, the propagation, transmission, processing and queuing delay times must be summed for all network devices in a particular network link and adjusted using the particular traffic type, packet size, and protocol type. For instance, packet latency is the time required for a packet to travel from transmitter to receiver. To predict packet latency for a particular link the propagation, transmission, processing and queuing delay times must be calculated using the specific network connection, traffic type, and packet size for the one-way transmission of a packet.

Round trip times are calculated similarly, except for the transmission and reception of a packet and the return of the acknowledging packet. Thus, to predict the round trip time, the invention takes into account the original packet size and the size of the acknowledging packet as well as the effects of the specific network connection, protocol and traffic type on the propagation, transmission, processing and queuing delays.

Handoff delay times are based on the propagation, transmission, processing and queuing delays involved in two separate wireless access points coordinating the change of control of a wireless device from one access point to another. These delays result because the two access points must transmit data back and forth to successfully perform a handoff. Thus, the prediction of handoff delay time is similar to the prediction of the packet latency time between the two access points. To predict the handoff delay time, the invention calculates the propagation, transmission, processing and queuing delays for the link between the two access points. The invention then adjusts for the specific number of transmissions required and the size of the data, which must be sent to successfully perform a handoff.

When predicting bit error rates, the invention considers wired and wireless error rates. Wireless networks operate in much more hostile electrical environments than their wired counterparts and their interconnections are significantly more difficult to model and, until this invention, practical networks have not successfully been modeled using specific, accurate physical and electrical models of multiple transmitters, multiple interferers, noise sources, and network components within a 3-D site-specific environment. This invention uses 3-D site specific representations of the environment for specific network implementations that are able to consider both wired and wireless networks, and considers physical locations, electrical specifications and attributes of all radiating sources and their antenna systems in a real-world 3-D environmental model. Wireless networks are prone to data errors much more so than wired channels, due to the impact of multipath propagation, multiple transmitters, and noise, as described previously. The fact that radio propagation and noise is more random than for fixed wired networks must be considered for practical design, and is modeled in this invention. For wired channels, bit error rates are simply a measure of the electrical, optical and electromagnetic parameters of a connection and are predicted using a statistical random variable, such as a Gaussian or Poisson random distribution, or other sensible distribution or algorithm known now or in the future, and this random variable is overlaid about the average, median, or typical performance of the network component or network subsystem. The network device or subsystem may include a single wireless node, such as a router or switch, or a complete interconnection of various routers, hubs, switches, wireless access points, and wireless client/server devices that communicate with the network. The network may be wired, wireless, or a combination thereof.

Many performance metrics of a device or a network subsystem, such as Frame Error Rate, Bit Error Rate, or Packet Error Rate, as well as other performance parameters such as throughput, bandwidth, quality of service, bit error rate, packet error rate, frame error rate, dropped packet rate, packet latency, round trip time, propagation delay, transmission delay, processing delay, queuing delay, network capacity, packet jitter, bandwidth delay product and handoff delay time may be either derived from a specification of the equipment, may be calculated analytically within the invention or inputted into the invention, or may be measured a priori in advance to using the invention. That is, specific parameters of operation, known as operating parameters or equipment parameters, such as those listed previously, can be either measured or predicted through equipment specifications provided by vendors. Alternatively, they may be measured in-situ by a user or research facility, for proper modeling and input into the invention. Alternatively, they may be calculated based on some known analytical model that contemplates interconnection of devices so that a performance model and operating parameters may be computed. The statistical random variable to model network performance within the invention can be dependant on the electrical, optical and electromagnetic characteristics of each device such as voltage levels, power levels, impedance,

and operating frequencies, or can be generated using a typical observed (measured) value for each network device. For instance, copper wire can be modeled as having a bit error rate of 1 error in 10^6 or 10^7 bits transmitted. Once measured and characterized a single initial time, a single component or a string of components within a network may be modeled repeatedly by the invention, so that network performance models.

Wireless performance parameters, however, are dependant on many more factors than wired bit error rates. For this reason, the invention predicts wireless bit error rates based on the environment, distance between transmitter and receiver, number and types of partitions obstructing the transmission, time, 3-D position, packet size, protocol type, modulation, radio frequency, radio frequency bandwidth, encoding method, error correction coding technique, multipath signal strengths and angle of arrival, and multipath delay. As a result, the calculation of the predicted bit error rate is performed using constants or functions to convert from previously measured or known channel and network equipment performance metrics to an expected bit error rate. A formulation for predicting the bit error rate, frame error rate or packet error rate directly for a data communications channel is shown in equation 4, and is identical to equation 1.

$$BER,\ PER,\ \text{or}\ FER = C_1[Ad + Bd^2 + C] + C_2[D(RSSI) + E(RSSI)^2 + F] + C_3\sum_{i=1}^{M}(G_iP_i + K_i) \tag{4}$$

where BER is bit error rate, FER is the frame error rate, PER is the packet error rate, d is the distance between a transmitter and a receiver. RSSI is the received signal strength intensity, which is the power level of the signal at the receiver. A, B, C, C_1, C_2, C_3, D, E, F, K_i, are constants or linear or non linear functions with different values depending on which of BER, FER, and PER is being calculated. The value M may denote particular number of multipath components from a particular transmitter, or may denote a combination of important multipath components from a collection of transmitters, where the term "important" is based on antenna pattern, physical environment distances, and other wireless propagation factors which are well known to one skilled in the art and which are explained within this disclosure. The each of M values of G_i and P_i represent gains and power levels, respectively, of different signal components, which may represent individual multipath components or gross signal components from one or more radiating sources, and may be in logarithmic or linear values of power. The variables G_i and P_i and each one of the M number of K_i values may be in logarithmic (e.g. dB) or absolute values. These constants in the above equation are dependant on distance (d) between transmitter and receiver where d may be the straight-line or actual reflected/diffracted distance of the main signal path between the serving transmitter and receiver. As explained in the text surrounding equation (1), distance may be straight-line distance, or may be modeled from the gross characteristics of the environment, such as the maximum, average, or median length of the 3-D environment. As with equation (1), equation (4) may consider the distance d as the actual physical distance, or as a relative distance referenced to a close-in reference.

Frame error rates, packet error rates and packet drop rates can all be calculated from bit error rates or predicted directly using the same method as for a bit error rate as described above or as modeled in equation 4. To perform these calculations the invention uses information stored in the site-specific Bill of Materials about the packet size, frame size and the protocol in use, and uses a site-specific propagation and interference modeling technique, such as that utilized in the SitePlanner product by Wireless Valley Communications, Inc.

In wireless networks, modeling the combined effects of all the various sources of errors is extremely difficult. Not only does modulation and specific error and source coding techniques impact the wireless network performance, but so does the impact of antennas, multipath, noise, voice over IP or wireless ATM concatenation methods, modem design of particular wireless modem makers, and the specific RF distribution system used to connect wired and wireless devices. The ability to model such varied effects can be done by allowing field measurement of specific in-situ network performance as explained earlier. By conducting a walk-through or a drive test whereby a mobile receiver is operated and network performance parameters are measured within the site-specific environment, it is then possible to determine best fits for particular modem manufacturers, applying concepts described in equation 1.

Bandwidth delay products can be calculated by the invention directly using information about any or all of the environment, three dimensional position, protocol type, multipath delay, packet sizes, radio frequency, radio frequency bandwidth, coding, number, strength and angle of arrival of multipath components, signal strength, transmission, propagation, processing and queuing delay, bit error rate, packet error rate, and frame error rates. Alternatively the invention can calculate the bandwidth delay product indirectly using previously predicted values. A bandwidth delay product is calculated by multiplying the bandwidth of a certain network device by the total delay introduced by that device. Thus, the formula is illustrated here in equation 5:

$$BWD = \frac{BW}{T_{net}} \tag{5}$$

Where BWD is the bandwidth delay product, BW is the bandwidth and T_{net} is the total delay introduced.

The invention uses statistical models of the consistency of data communications network hardware to predict packet jitter and quality of service (QoS). Both of these performance criterions are measures of the reliability of a network to provide consistent data arrival times. Thus, to calculate the QoS or jitter of a connection, the invention uses formulas which include any or all of the environment, three dimensional position, protocol type, multipath delay, packet sizes, radio frequency, radio frequency bandwidth, coding, number, strength and angle of arrival of multipath components, signal strength, transmission, propagation, processing and queuing delay, bit error rate, packet error rate, frame error rate, throughput, bandwidth, and bandwidth delay product. The formulas include constants or functions, which relate the above variables in general to the variation in the arrival time of data and in specific to the QoS and packet jitter of a connection. The present embodiment of the current invention uses equations (1) or (4) to determine QoS and packet jitter for a data communications network.

The preferred embodiment of the invention predictions consider the effects of not just the site specific, floor plan, building layout, terrain characteristics and RF characteris-

tics, but also the effects of the particular network hardware, firmware and software in the network. The invention allows the network to be modeled down to the settings and locations of the individual data communications devices, using the Bill of Materials discussed earlier. The prediction of network performance statistics takes these settings into account. This means that different transport level protocols (such as TCP or UDP), different protocol settings (such as packet and buffer sizes), the data bandwidth (in bits per second), physical layer transmission methods including modulation techniques (such as QPSK or FHSS), coding schemes (such as CCK or trellis codes), transport media (such as copper, fiber optic cable or wireless connections) and specific frequency bands are taken into account by the invention. These aspects are in addition to the consideration of the location and wireless specific criteria, which includes transmitter-receiver distance (T-R distance), the propagation environment, interference, path loss, number of users sharing the RF resources, multipath delay, the number of multipath components and their strengths and angle of arrival, the ratio of coherent to incoherent power, and the RF bandwidth (in Hz). All of these variables may produce results which may be mapped into the form of equation (1) or (4).

The predictions of the preferred form of the invention consider the characteristics of the data communications network users. Information such as the type of data communications traffic the users offer to the network, the number of users, and the usage patterns over time, are stored in a location specific manner in the invention. That is, points can be placed which represent individual users and the traffic offered by that user or areas in which the characteristics of a group or pool of users can be assigned. The invention takes these points and areas of user traffic into account when making predictions of network performance criterions. This means that if large numbers of users are found in an area covered by access points that are able to adapt to heavy usage, the invention is able to accurately predict the performance of these (or any other) conditions. This is only possible because of the accurate, location specific model of the data communication network. Additionally, since the preferred form of the invention tracks usage patterns of users over time, the resulting measurements may be used by a server processor to form table look-up values for the constants or functions of Equations (1) or (4). Different values of constants or functions for Equations (1) or (4) may be found to predict the performance of the network at different times of day. This is an important aspect of a data communication network prediction model because real networks have peak usage times and lulls in which usage is lower. By tracking the usage of a data communications network over time, the preferred form of the invention can determine if the network will have difficulties at certain times.

In a communications network, the capacity is always a scaled version of the theoretical maximum possible capacity, and the impact of various users, and their propagation characteristics, message sizes, as well as the network characteristics, all combine to bound or limit the capacity that an individual user sees on a network. Consider a network that has, as a bottleneck, a particular component or device which has a maximum rating of Tmax bits per second. This component bounds the maximum possible throughput of the network. Consider that capacity represents the capacity or throughput of a device or network (defined as T or Capacity), where T(x,y,z, t)=Tmax[γ], where y is a scaling factor that fuses many different, complicated physical, electrical, and logical conditions into a simple value that ranges between 0 and 1. When gamma is 0, there is no capacity. When gamma is 1, there is maximum capacity. Note that T is a function of 3-D positioning in the network, as well as a function of time. For a particular user, the goal of a network predictive model is to predict the capacity, as a function of 3-D position and as a function of time. Thus, T[x,y,z,t] will range between 0 and T_{max}.

The load put on to a data communications network impacts the capacity of an individual user. The number of users and the usage patterns of each user affect the capacity of each user in a data communications network. The preferred embodiment of the invention allows a network designer to see the effects of network loading on the important network statistics, by measuring the instantaneous traffic conditions with the measurement agents as described above. It is possible to determine in-situ capacity measurements through other means, such as observation from network equipment o reporting mechanisms built into hardware or software products. By forming a table look-up of the specific capacity results, as a function of 3-D site-specific location, as well as the time of day, the invention builds a measurement-based predictive model for capacity. These measurements may be used to form a model of capacity, as now presented.

The invention contemplates the fact that the scaling factor on capacity (or throughput), is a function of the instantaneous number of users of the network, the maximum number of simultaneous users of the network, the average and maximum packet size used by users of the network, and for many other factors that are modem or network or vendor or protocol specific. Also, in the case of a wireless network, the multipath propagation effects, the propagation distances between the user and the wireless access points, and the received signal levels are factors that limit capacity. In addition, constants or functions that fuse the impact of modulation, equalizations, impulse noise, and other factors, are used in the invention.

Thus, capacity or throughput of a network is modeled by

$$\text{Capacity} = C_1[Ad + Bd^2 + C] + C_2[D(RSSI) + E(RSSI)^2 + F] + C_3\sum_{i=1}^{M}(G_iP_i + K_i) \tag{6}$$

where the constants or functions of (6) take on similar properties as described for equations (1) and (4). Furthermore, the entire equation (6) may be scaled by K/Umax, where K is the instantaneous number of users on the network, and Umax denotes the maximum number of simultaneous users possible.

Handoff delay times are potential problems in wireless data communication networks. A handoff occurs in wireless data networks when a user moves out of range of one access point and into range of another access point. In this situation, the first access point must pass the responsibility of delivering data to the wireless user to the second access point. If the two access points are too far apart, there will not be enough time for a wireless data network user to be handed off from one access point to another and file transfers can fail. The invention predicts where handoffs will occur and the possibility of handoff failures due to incompatible network settings at two different access points by using site-specific time dependent measurements, and fitting them into a form of equation (1), (4) or (6). Then, a table look up method is used to determine prediction models for handoff times as a function of spatial positioning and time of day.

The concept of optimization is a key aspect of the invention. The preferred invention is highly effective at allowing one skilled in the art to quickly improve the performance of an existing data communications network by comparing measured performance parameters with predicted values that are derived and stored in the invention. The process of using measurements to improve predictions is called optimization and is illustrated in FIG. **6**, FIG. **7**, and FIG. **8**. The method for optimizing a network using just measurements is shown in FIG. **6**, just predictions in FIG. **7**, and a combination of measurements and predictions in FIG. **8**. The process of optimizing a data communications network is accomplished by comparing, through numerical, visual, or some other means, the predictions and measurements of performance criteria such as throughput, bandwidth, quality of service, bit error rate, packet error rate, frame error rate, dropped packet rate, packet latency, round trip time, propagation delay, transmission delay, processing delay, queuing delay, network capacity, packet jitter, bandwidth delay product and handoff delay time for various site-specific locations and particular times of day. By changing the hardware used in the network, or changing the locations of hardware or the configuration of that hardware, firmware, or software which controls each device within the network, one skilled in the art can improve the performance of the network. These performance improvements can implemented and viewed by repeating predictions of the performance criteria after site-specific equipment changes to the network have been made in the 3-D model of the network. Continuing this process allows one skilled in the art to optimize the performance of a network to achieve an efficient data communications network.

Using this information, the preferred embodiment of the invention can make recommendations for the areas of the network to upgrade or reconfigure. The invention can also use SNMP protocol communications or other protocols to actually implement these changes. That is, a network designer could identify problems in a data communications network through prediction, whereby the prediction of performance criteria of the data communications network is calculated using known measurement data and the configuration and expected performance of all data communications hardware in the data communications network. The predicted performance criterion is stored and displayed visually and numerically in a location specific, three-dimensional model of the environment. Then, the designer can use the invention to identify a solution to the problems that are apparent by viewing the prediction results, either by following the inventions recommendations for changes or making the designers own change. After simulating the predicted outcome, the network designer can then direct the invention to update all the relevant settings of the equipment with the changes the designer has just used in a prediction. The designer could then use the tool to measure the results of these changes using the measurement features of the invention.

While this invention has been described in terms of its preferred embodiments, those skilled in the art will recognize that the invention can be practiced with considerable variation within the scope of the appended claims.

What is claimed is:

1. A method for analyzing and adjusting a wireless communications network, comprising the steps of:

generating or using, with a computer or server, a computerized model of a wireless communications network within a physical space in which said wireless communications network is deployed, said computerized model providing a site specific representation of one or more of a floor plan, building layout, terrain characteristics, or RF characteristics, said computerized model identifying locations within said physical space of one or more components used in said wireless communications network, said computerized model having modeled attributes for at least one each of said one or more components;

receiving, at said computer or server, measurement data from one or more measurement collectors or agents located in said physical space, said one or more measurement collectors or agents being the same or different from one or more of said one or more components used in said wireless communications network;

predicting, at said computer or server, one or more performance metrics for said wireless communications network, wherein predictions are made based on said modeled attributes for said at least one of said one or more components, and said measurement data from said one or more measurement collectors or agents; and

changing settings or configurations of at least one component of said wireless communications network based on instructions sent from said computer or server.

2. The method of claim **1** wherein said site specific representation is three dimensional.

3. The method of claim **1** wherein said data collection measurement collectors or agents are portable or fixed.

4. The method of claim **1** further comprising the step of affixing said measurement collectors or agents permanently within said physical space.

5. The method of claim **1** wherein said performance metric predicted in said predicting step is selected from the group consisting of throughput, error rates, packet latency, packet jitter, symbol jitter, quality of service, security, coverage area, bandwidth, bit error rate, packet error rate, frame error rate, dropped packet rate, queuing delay, round trip time, capacity, signal level, interference level, bandwidth delay product, handoff delay time, signal-to-interface ratio, signal-to-noise ratio, physical equipment price, and cost information.

6. The method of claim **1** wherein said measurement data received in said receiving step obtained manually.

7. The method of claim **1** wherein said measurement data received in said receiving step obtained autonomously.

8. The method of claim **1** further comprising the step of storing said measurement data.

9. The method of claim **1** further comprising the step of updating said computerized model.

10. The method of claim **9** wherein said step of updating includes the steps of:

specifying components from a plurality of different modeled components which are to be used in said communications network, said modeled components including descriptions and attributes of a specific component; and

specifying locations within said physical space for a plurality of different components in said computerized model.

11. The method of claim **10** wherein said step of updating further includes the step of specifying an orientation for at least one component specified in said first specifying step at said location specified in said second specifying step.

12. The method of claim **1** wherein said computerized model identifies orientations of said components at said locations within said physical space and said predicting step utilizes said orientations.

13. The method of claim **1** wherein said computerized model includes one or more objects which create noise or

interference, said noise or interference being an attribute of said one or more objects which are factored in said predicting step.

14. The method of claim **1** wherein said one or more performance metrics predicted in said predicting step are predicted in a forward direction in said wireless communication network.

15. The method of claim **1** wherein said one or more performance metrics predicted in said predicting step are predicted in a reverse direction in said wireless communication network.

16. The method of claim **1** further comprising the step of specifying data transfer protocol, and wherein said predicting step uses a specified data transfer protocol as a factor in predicting said one or more performance metrics.

17. The method of claim **1** further comprising the step of specifying a network loading for said wireless communications network, and wherein said predicting step uses a specified network loading in predicting said one or more performance metrics.

18. The method of claim **1** further comprising the step of storing or visualizing data representing comparisons of measurements with predictions.

19. The method of claim **1** further comprising the step of storing or visualizing data representing either or both logical connections of network components or physical locations of network components.

20. A system or apparatus for analyzing and adjusting a wireless communications network, comprising:

a computer or server for generating or using a computerized model of a wireless communications network positioned within a physical space, said computerized model providing a site specific representation of one or more of a floor plan, building layout, terrain characteristics, or RF characteristics, said computerized model identifying locations within said physical space of one or more components used in said wireless communications network, said computerized model having modeled attributes for at least one of said one or more components;

one or more measurement collectors or agents operating or operational within said physical space which send measurement data to said computer or server, said computer or server predicting one or more performance metrics for said wireless communications network based on said measurement data and said modeled attributes for said at least one of said one or more components, and said computer or server can send instructions to one or more components of said wireless communications network which cause settings or configurations of at least one component to be changed.

21. The system or apparatus of claim **20** wherein said site specific representation is three dimensional.

22. The system or apparatus of claim **20** wherein said measurement collectors or agents are portable or fixed.

23. The system or apparatus of claim **20** wherein said measurement collectors or agents are permanently affixed at within said physical space.

24. The system or apparatus of claim **20** wherein said performance metric predicted by said computer or server is selected from the group consisting of throughput, error rates, packet latency, packet jitter, symbol jitter, quality of service, security, coverage area, bandwidth, bit error rate, packet error rate, frame error rate, dropped packet rate, queuing delay, round trip time, capacity, signal level, interference level, bandwidth delay product, handoff delay time, signal-to-interface ratio, signal-to-noise ratio, physical equipment price, cost information.

25. The system or apparatus of claim **20** further comprising a storage device for storing said measurement data.

26. The system or apparatus of claim **20** wherein said computerized model is stored on at least one server, wherein said at least one server is the same or different from said computer or server.

27. The system or apparatus of claim **26** wherein said computerized model is stored on a plurality of servers, and said plurality of servers can communicate with each other.

28. The system or apparatus of claim **27** wherein said plurality of servers have a heirarchical relationship to one another.

29. The system or apparatus of claim **26** further comprising at least one portable client device, said at least one portable client device can communicate with said at least one server.

30. The system or apparatus of claim **28** wherein said system includes a plurality of portable client devices.

31. The system or apparatus of claim **20** further comprising a storage medium or display for, respectively, storing or visualizing data representing comparisons of measurements with predictions.

32. The system or apparatus of claim **20** further comprising a storage medium or display for, respectively, storing or visualizing either or both logical connections of network components or physical locations of network components.

33. A method for analyzing and adjusting a wireless communications network, comprising the steps of:

generating or using, with a computer or server, a computerized model of a wireless communications network within a physical space in which said communications network is deployed, said computerized model providing a site specific representation of one or more of a floor plan, building model, terrain characteristics, or RF characteristics, said computerized model identifying locations within said physical space of one or more components used in said wireless communications network, said computerized model having modeled attributes for at least one of said one or more components;

downloading or inputting files of measurement data to said computer or server, where said measurement data is obtained from said physical space or from said wireless communications network;

predicting or providing a one or more performance metrics for said wireless communications network based on said measurement data and said modeled attributes for said at least one of said one or more components; and

changing settings or configurations of at least one component of said wireless communications network based on instructions sent from said computer or server.

34. The method of claim **33** wherein said measurement data is obtained from measurement collectors or agents that are either portable or fixed.

35. The method of claim **33** further comprising the step of storing or visualizing data representing comparisons of measurements with predictions.

36. The method of claim **33** further comprising the step of storing or visualizing data representing either or both logical connections of network components or physical locations of network components.

37. A site specific method for analyzing and adjusting a communications network, comprising the steps of:

generating or using, with a computer or server, a computerized model of a communications network positioned within a physical space, said computerized model providing a site specific representation of one or more of a floor plan, building layout, terrain characteristics or RF characteristics, said computerized model identifying locations within said physical space of one or more components used in said communications network, said computerized model having modeled attributes for at least one of said one or more components

receiving, at said computer or server, measurement data from one or more measurement collectors or agents located in said physical space, said one or more measurement collectors or agents being the same or different from one or more of said one or more components used in said communications network;

predicting, using said computer or server, one or more performance metrics for said communications network, wherein predictions are made based on said measurement data and said modeled attributes for at least one of said one or more components;

changing settings or configurations of at least one component of said communications network based on instructions sent from said computer or server.

38. The method of claim **37** wherein said site specific representation is three dimensional.

39. The method of claim **37** wherein said measurement collectors or agents portable or fixed.

40. The method of claim **37** further comprising the step of affixing said measurement collectors or agents permanently within said physical space.

41. The method of claim **37** wherein said one or more performance metrics predicted in said predicting step are selected from the group consisting of one or more performance metrics are selected from radio signal strength intensity, connectivity, network throughput, bit error rate, frame error rate, signal-to-interference ratio, signal-to-noise ratio, frame resolution per second, traffic, capacity, signal strength, throughput, error rates, packet latency, packet jitter, symbol jitter, quality of service, security, coverage area, bandwidth, server identification parameters, transmitter identification parameters, best server locations, transmitter location parameters, billing information, network performance parameters, C/I, C/N, body loss, height above floor, height above ground, noise figure, secure coverage locations, propagation loss factors, angle of arrival, multipath components, multipath parameters, antenna gains, noise level reflectivity, surface roughness, path loss models, attenuation factors, throughput performance metrics, packet error rate, round trip time, dropped packet rate, queuing delay, signal level, interference level, quality of service, bandwidth delay product, handoff delay time, signal loss, data loss, number of users serviced, user density, locations of adequate coverage, handoff locations or zones, locations of adequate throughput, E_c/I_o, system performance parameters, equipment price, maintenance and cost information, user class or subclass, user type, position location, all in either absolute or relative terms.

42. The method of claim **37** wherein said measurement data received in said receiving step is obtained manually.

43. The method of claim **37** wherein said measurement data received in said receiving step is obtained autonomously.

44. The method of claim **37** further comprising the step of storing said measurement data.

45. The method of claim **37** further comprising the step of updating said computerized model.

46. The method of claim **45** wherein said step of updating includes the steps of:

specifying components from a plurality of different modeled components which are to be used in said communications network, said modeled components including descriptions and attributes of a specific component; and

specifying locations within said space for a plurality of different components in said computerized model.

47. The method of claim **46** wherein said step of updating further includes the step of specifying an orientation for at least one component specified in said specifying components step at said location specified in said specifying locations step.

48. The method of claim **37** wherein said computerized model identifies orientations of one or more of said one or more components at said locations within said physical space and said predicting step utilizes said orientations.

49. The method of claim **37** wherein said computerized model includes one or more objects which create noise or interference, said noise or interference being an attribute of said one or more objects which are factored in said predicting step.

50. The method of claim **37** wherein said one or more performance metrics predicted in said predicting step are predicted in a forward direction in said communication network.

51. The method of claim **37** wherein said one or more performance metrics predicted in said predicting step are predicted in a reverse direction in said communication network.

52. The method of claim **37** further comprising the step of specifying data transfer protocol, and wherein said predicting step uses a specified data transfer protocol as a factor in predicting said performance metric.

53. The method of claim **37** further comprising the step of specifying a network loading for said communications network, and wherein said predicting step uses a specified network loading in predicting said one or more performance metrics.

54. The method of claim **37** further comprising the step of storing or visualizing data representing comparisons of measurements with predictions.

55. The method of claim **37** further comprising the step of storing or visualizing data representing either or both logical connections of network components or physical locations of network components.

56. A site specific system or apparatus for analyzing and adjusting a communications network, comprising:

a computer or server for generating or using a computerized model of a communications network positioned within a physical space, said computerized model providing a site specific representation of one or more of a floor plan, building layout, terrain characteristics or RF characteristics, said computerized model identifying locations within said physical space of one or more components used in said communications network, said computerized model having modeled attributes for at least one of said one or more components;

one or more measurement collectors or agents positioned within said physical space which obtain and send measurement data to said computer or server, said computer or server predicting one or more performance metrics for said communications network based on said measurement data and said modeled attributes for said at least one of said one or more components, and said

computer or server can send instructions to one or more components of said communications network which cause settings or configurations of at least one component to be changed.

57. The system or apparatus of claim **56** wherein said site specific representation is three dimensional.

58. The system or apparatus of claim **56** wherein said measurement collectors or agents are portable or fixed.

59. The system or apparatus of claim **56** wherein said measurement collectors or agents are permanently affixed at locations within said physical space.

60. The system or apparatus of claim **56** wherein said one or more performance metrics selected from the group consisting of one or more performance metrics are selected from radio signal strength intensity, connectivity, network throughput, bit error rate, frame error rate, signal-to-interference ratio, signal-to-noise ratio, frame resolution per second, traffic, capacity, signal strength, throughput, error rates, packet latency, packet jitter, symbol jitter, quality of service, security, coverage area, bandwidth, server identification parameters, transmitter identification parameters, best server locations, transmitter location parameters, billing information, network performance parameters, C/I, C/N, body loss, height above floor, height above ground, noise figure, secure coverage locations, propagation loss factors, angle of arrival, multipath components, multipath parameters, antenna gains, noise level reflectivity, surface roughness, path loss models, attenuation factors, throughput performance metrics, packet error rate, round trip time, dropped packet rate, queuing delay, signal level, interference level, quality of service, bandwidth delay product, handoff delay time, signal loss, data loss, number of users serviced, user density, locations of adequate coverage, handoff locations or zones, locations of adequate throughput, E_c/I_0, system performance parameters, equipment price, maintenance and cost information, user class or subclass, user type, position location, all in either absolute or relative terms.

61. The system or apparatus of claim **56** further comprising a storage device for storing said measurement data.

62. The system or apparatus of claim **56** wherein said computerized model is stored on at least one server which may be the same or different from said computer or server.

63. The system or apparatus of claim **62** wherein said computerized model is stored on a plurality of servers, wherein said plurality of servers can communicate with each other.

64. The system or apparatus of claim **63** wherein said plurality of servers have a heirarchical relationship to one another.

65. The system or apparatus of claim **62** further comprising at least one portable client device that can communicate with said at least one server.

66. The system or apparatus of claim **64** wherein said system includes a plurality of portable client devices.

67. The system or apparatus of claim **56** further comprising a storage medium or display for, respectively, storing or visualizing data representing comparisons of measurements with predictions.

68. The system or apparatus of claim **56** further comprising a storage medium or display for, respectively, storing or visualizing either or both logical connections of network components or physical locations of network components.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,973,622 B1
APPLICATION NO. : 09/668145
DATED : December 6, 2005
INVENTOR(S) : Rappaport et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 30, line 7 change "each of" to --of--

Column 30, line 38 change "interface" to --interference --

Column 30, line 42 insert "is" after "step"

Column 30, line 44 insert "is" after "step"

Column 32, line 2 change "interface" to --interference--

Column 32, line 21 insert "or apparatus" after "system"

Column 32, line 48 delete "a"

Column 33, lines 36, 37 delete "one or more performance metrics are selected from"

Column 35, line 14 delete "one or more performance metrics are selected from"

Signed and Sealed this

Fifth day of September, 2006

Jon W. Dudas

JON W. DUDAS
Director of the United States Patent and Trademark Office

JS 44 (Rev. 3/99)

CIVIL COVER SHEET

The JS-44 civil cover sheet and the information contained herein neither replace nor supplement the filing and service of pleadings or other papers as required by law, except as provided by local rules of court. This form, approved by the Judicial Conference of the United States in September 1974, is required for the use of the Clerk of Court for the purpose of initiating the civil docket sheet. (SEE INSTRUCTIONS ON THE REVERSE OF THE FORM.)

I. (a) PLAINTIFFS

SYMBOL TECHNOLOGIES, INC. and WIRELESS VALLEY COMMUNICATIONS, INC.

(b) County of Residence of First Listed Plaintiff Suffolk, New York
(EXCEPT IN U.S. PLAINTIFF CASES)

(c) Attorney's (Firm Name, Address, and Telephone Number)

Richard L. Horwitz (#2246)
Potter Anderson & Corroon LLP
1313 N. Market Street
Wilmington, Delaware 19801 (302) 984-6000

DEFENDANTS

ARUBA NETWORKS, INC.

County of Residence of First Listed Defendant Santa Clara
(IN U.S. PLAINTIFF CASES ONLY)
NOTE: IN LAND CONDEMNATION CASES, USE THE LOCATION OF THE LAND INVOLVED.

Attorneys (If Known)

II. BASIS OF JURISDICTION (Place an "X" in One Box Only)

- [ ] 1 U.S. Government Plaintiff
- [x] 3 Federal Question (U.S. Government Not a Party)
- [ ] 2 U.S. Government Defendant
- [ ] 4 Diversity (Indicate Citizenship of Parties in Item III)

III. CITIZENSHIP OF PRINCIPAL PARTIES (Place an "X" in One Box for Plaintiff and One Box for Defendant) (For Diversity Cases Only)

	PTF	DEF		PTF	DEF
Citizen of This State	1	1	Incorporated *or* Principal Place of Business In This State	4	4
Citizen of Another State	2	2	Incorporated *and* Principal Place of Business In Another State	5	5
Citizen or Subject of a Foreign Country	3	3	Foreign Nation	6	6

IV. NATURE OF SUIT (Place an "X" in One Box Only)

CONTRACT
- [ ] 110 Insurance
- [ ] 120 Marine
- [ ] 130 Miller Act
- [ ] 140 Negotiable Instrument
- [ ] 150 Recovery of Overpayment & Enforcement of Judgment
- [ ] 151 Medicare Act
- [ ] 152 Recovery of Defaulted Student Loans (Excl. Veterans)
- [ ] 153 Recovery of Overpayment of Veteran's Benefits
- [ ] 160 Stockholders' Suits
- [ ] 190 Other Contract
- [ ] 195 Contract Product Liability

REAL PROPERTY
- [ ] 210 Land Condemnation
- [ ] 220 Foreclosure
- [ ] 230 Rent Lease & Ejectment
- [ ] 240 Torts to Land
- [ ] 245 Tort Product Liability
- [ ] 290 All Other Real Property

TORTS

PERSONAL INJURY
- [ ] 310 Airplane
- [ ] 315 Airplane Product Liability
- [ ] 320 Assault, Libel & Slander
- [ ] 330 Federal Employers' Liability
- [ ] 340 Marine
- [ ] 345 Marine Product Liability
- [ ] 350 Motor Vehicle
- [ ] 355 Motor Vehicle Product Liability
- [ ] 360 Other Personal Injury

PERSONAL INJURY
- [ ] 362 Personal Injury— Med. Malpractice
- [ ] 365 Personal Injury — Product Liability
- [ ] 368 Asbestos Personal Injury Product Liability

PERSONAL PROPERTY
- [ ] 370 Other Fraud
- [ ] 371 Truth in Lending
- [ ] 380 Other Personal Property Damage
- [ ] 385 Property Damage Product Liability

CIVIL RIGHTS
- [ ] 441 Voting
- [ ] 442 Employment
- [ ] 443 Housing/ Accommodations
- [ ] 444 Welfare
- [ ] 440 Other Civil Rights

PRISONER PETITIONS
- [ ] 510 Motions to Vacate Sentence
- Habeas Corpus:
- [ ] 530 General
- [ ] 535 Death Penalty
- [ ] 540 Mandamus & Other
- [ ] 550 Civil Rights
- [ ] 555 Prison Condition

FORFEITURE/PENALTY
- [ ] 610 Agriculture
- [ ] 620 Other Food & Drug
- [ ] 625 Drug Related Seizure of Property 21 USC
- [ ] 630 Liquor Laws
- [ ] 640 R.R. & Truck
- [ ] 650 Airline Regs.
- [ ] 660 Occupational Safety/Health
- [ ] 690 Other

LABOR
- [ ] 710 Fair Labor Standards Act
- [ ] 720 Labor/Mgmt. Relations
- [ ] 730 Labor/Mgmt.Reporting & Disclosure Act
- [ ] 740 Railway Labor Act
- [ ] 790 Other Labor Litigation
- [ ] 791 Empl. Ret. Inc. Security Act

BANKRUPTCY
- [ ] 422 Appeal 28 USC 158
- [ ] 423 Withdrawal 28 USC 157

PROPERTY RIGHTS
- [ ] 820 Copyrights
- [x] 830 Patent
- [ ] 840 Trademark

SOCIAL SECURITY
- [ ] 861 HIA (1395ff)
- [ ] 862 Black Lung (923)
- [ ] 863 DIWC/DIWW (405(g))
- [ ] 864 SSID Title XVI
- [ ] 865 RSI (405(g))

FEDERAL TAX SUITS
- [ ] 870 Taxes (U.S. Plaintiff or Defendant)
- [ ] 871 IRS—Third Party 26 USC 7609

OTHER STATUTES
- [ ] 400 State Reapportionment
- [ ] 410 Antitrust
- [ ] 430 Banks and Banking
- [ ] 450 Commerce/ICC Rates/etc.
- [ ] 460 Deportation
- [ ] 470 Racketeer Influenced and Corrupt Organizations
- [ ] 810 Selective Service
- [ ] 850 Securities/Commodities/ Exchange
- [ ] 875 Customer Challenge 12 USC 3410
- [ ] 891 Agricultural Acts
- [ ] 892 Economic Stabilization Act
- [ ] 893 Environmental Matters
- [ ] 894 Energy Allocation Act
- [ ] 895 Freedom of Information Act
- [ ] 900Appeal of Fee Determination Under Equal Access to Justice
- [ ] 950 Constitutionality of State Statutes
- [ ] 890 Other Statutory Actions

V. ORIGIN (PLACE AN "X" IN ONE BOX ONLY)

- [x] 1 Original Proceeding
- [ ] 2 Removed from State Court
- [ ] 3 Remanded from Appellate Court
- [ ] 4 Reinstated or Reopened
- [ ] 5 Transferred from another district (specify)
- [ ] 6 Multidistrict Litigation
- [ ] 7 Appeal to District Judge from Magistrate Judgment

VI. CAUSE OF ACTION (Cite the U.S. Civil Statute under which you are filing and write brief statement of cause. Do not cite jurisdictional statutes unless diversity.)

35 U.S.C § 271 for patent infringement and 28 U.S.C. § 1338(a).

VII. REQUESTED IN COMPLAINT:

- [ ] CHECK IF THIS IS A CLASS ACTION UNDER F.R.C.P. 23

DEMAND $

CHECK YES only if demanded in complaint:
JURY DEMAND: [x] Yes [ ] No

VIII. RELATED CASE(S) IF ANY (See instructions):

JUDGE ______ DOCKET NUMBER ______

DATE 08/27/2007 SIGNATURE OF ATTORNEY OF RECORD

Richard L. Horwitz by [illegible] (2983)

FOR OFFICE USE ONLY

RECEIPT # ______ AMOUNT ______ APPLYING IFP ______ JUDGE ______ MAG. JUDGE ______

JS 44 Reverse (Rev. 12/96)

INSTRUCTIONS FOR ATTORNEYS COMPLETING CIVIL COVER SHEET FORM JS-44

Authority For Civil Cover Sheet

The JS-44 civil cover sheet and the information contained herein neither replaces nor supplements the filings and service of pleading or other papers as required by law, except as provided by local rules of court. This form, approved by the Judicial Conference of the United States in September 1974, is required for the use of the Clerk of Court for the purpose of initiating the civil docket sheet. Consequently, a civil cover sheet is submitted to the Clerk of Court for each civil complaint filed. The attorney filing a case should complete the form as follows:

I. **(a) Plaintiffs-Defendants.** Enter names (last, first, middle initial) of plaintiff and defendant. If the plaintiff or defendant is a government agency, use only the full name or standard abbreviations. If the plaintiff or defendant is an official within a government agency, identify first the agency and then the official, giving both name and title.

(b.) County of Residence. For each civil case filed, except U.S. plaintiff cases, enter the name of the county where the first listed plaintiff resides at the time of filing. In U.S. plaintiff cases, enter the name of the county in which the first listed defendant resides at the time of filing. (NOTE: In land condemnation cases, the county of residence of the "defendant" is the location of the tract of land involved.)

(c) Attorneys. Enter the firm name, address, telephone number, and attorney of record. If there are several attorneys, list them on an attachment, noting in this section "(see attachment)".

II. Jurisdiction. The basis of jurisdiction is set forth under Rule 8(a), F.R.C.P., which requires that jurisdictions be shown in pleadings. Place an "X" in one of the boxes. If there is more than one basis of jurisdiction, precedence is given in the order shown below.

United States plaintiff. (1) Jurisdiction based on 28 U.S.C. 1345 and 1348. Suits by agencies and officers of the United States, are included here.

United States defendant. (2) When the plaintiff is suing the United States, its officers or agencies, place an "X" in this box.

Federal question. (3) This refers to suits under 28 U.S.C. 1331, where jurisdiction arises under the Constitution of the United States, an amendment to the Constitution, an act of Congress or a treaty of the United States. In cases where the U.S. is a party, the U.S. plaintiff or defendant code takes precedence, and box 1 or 2 should be marked.

Diversity of citizenship. (4) This refers to suits under 28 U.S.C. 1332, where parties are citizens of different states. When Box 4 is checked, the citizenship of the different parties must be checked. (See Section III below; federal question actions take precedence over diversity cases.)

III. Residence (citizenship) of Principal Parties. This section of the JS-44 is to be completed if diversity of citizenship was indicated above. Mark this section for each principal party.

IV. Nature of Suit. Place an "X" in the appropriate box. If the nature of suit cannot be determined, be sure the cause of action, in Section IV below, is sufficient to enable the deputy clerk or the statistical clerks in the Administrative Office to determine the nature of suit. If the cause fits more than one nature of suit, select the most definitive.

V. Origin. Place an "X" in one of the seven boxes.

Original Proceedings. (1) Cases which originate in the United States district courts.

Removed from State Court. (2) Proceedings initiated in state courts may be removed to the district courts under Title 28 U.S.C., Section 1441. When the petition for removal is granted, check this box.

Remanded from Appellate Court. (3) Check this box for cases remanded to the district court for further action. Use the date of remand as the filing date.

Reinstated or Reopened. (4) Check this box for cases reinstated or reopened in the district court. Use the reopening date as the filing date.

Transferred from Another District. (5) For cases transferred under Title 28 U.S.C. Section 1404(a) Do not use this for within district transfers or multidistrict litigation transfers.

Multidistrict Litigation. (6) Check this box when a multidistrict case is transferred into the district under authority of Title 28 U.S.C. Section 1407. When this box is checked, do not check (5) above.

Appeal to District Judge from Magistrate Judgment. (7) Check this box for an appeal from a magistrate judge's decision.

VI. Cause of Action. Report the civil statute directly related to the cause of action and give a brief description of the cause.

VII. Requested in Complaint. Class Action. Place an "X" in this box if you are filing a class action under Rule 23, F.R.Cv.P.

Demand. In this space enter the dollar amount (in thousands of dollars) being demanded or indicate other demand such as a preliminary injunction.

Jury Demand. Check the appropriate box to indicate whether or not a jury is being demanded.

VIII. Related Cases. This section of the JS-44 is used to reference related pending cases if any. If there are related pending cases, insert the docket numbers and the corresponding judge names for such cases.

Date and Attorney Signature. Date and sign the civil cover sheet.

AO FORM 85 RECEIPT (REV. 9/04)

United States District Court for the District of Delaware

Civil Action No. 07-519

FILED
CLERK U.S. DISTRICT COURT
DISTRICT OF DELAWARE
2007 AUG 27 AM 11:24

ACKNOWLEDGMENT OF RECEIPT FOR AO FORM 85

NOTICE OF AVAILABILITY OF A UNITED STATES MAGISTRATE JUDGE TO EXERCISE JURISDICTION

I HEREBY ACKNOWLEDGE RECEIPT OF 3 COPIES OF AO FORM 85.

AUG 27 2007
(Date forms issued)

Mike Bobish
(Signature of Party or their Representative)

Mike Bobish
(Printed name of Party or their Representative)

Note: Completed receipt will be filed in the Civil Action